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FINAL REPORT ON ALL SHUTTLE CENTAUR ENGINE AND NOZZLE SUPPORT PLUG VIBRATION TESTING

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FOREWORD

This report presents the results of the vibration testing of the RL10 engine and nozzle support plug for the Shuttle/Centaur program. The testing was conducted by Pratt & Whitney, Government Products Division (P&W/GPD) of the United Technologies Corporation (UTC) for the National Aeronautics and Space Administration Lewis Research Center (NASA/LeRC) under contract NAS3-23791.

This testing was conducted during the period of March 1985 through January 1986. The testing effort was conducted under the direction of LeRC Space Flight Systems Directorate with Mr. James A. Burkhart as Contracting Officer Representative. The effort at P&W/GPD was carried out under the direction of Mr. Robert Marable and Mr. Dennis Mills, Assistant Project Engineers.

CONTENTS

SECTION 1.0
INTRODUCTION

Loads applied to the RL10 engines while in flight in the orbiter payload bay are significantly different from the load environment experienced in Atlas and Titan/Centaur applications. To predict the engine loads, NASA and General Dynamics conducted a NASTRAN analysis. As part of this effort a vibration test program was accomplished to provide input to the analysis, and to verify engine durability. This program was completed in two phases. The first phase provided data and characteristics which were used as input to the NASA/General Dynamics analysis. The second phase subjected the engine to limit loads, and included hot firings before and after the vibration test.

This report describes the test hardware, tests performed and the test results.

SECTION 2.0
PHASE I — SINUSOIDAL VIBRATION TEST

Development engine XR104-1 was built as an RL10A-3-3A for vibration testing in May 1985. This was the same engine used for the RL10A-3-3A qualification vibration test. It was not configured for hot firing, but it did contain Shuttle/Centaur unique hardware including vehicle-supplied gearbox vent tube, cooldown valve vent ducts, and a functioning hydraulic actuation system. The hydraulic system was to be operated in the recirculation mode during some tests to determine if any useful damping could be provided by the actuators.

A fixture was built to hold the engine in a manner similar to that in the STS/Centaur configuration shown in Figure 1.

The engine and nozzle support plug were mounted in the fixture as shown in Figure 2.

The program consisted of sine sweeps from 500 to 5 Hz in the STS pitch direction (Centaur yaw direction) increasing in amplitude until a limit was reached. This limit was either a stress limit, a load limit in the actuators, or a deflection limit. Several different configurations were run, such as with flight hydraulic actuators, or with solid actuator rods. Table 1 contains a listing of the test steps and configurations followed during the test. Steps 10 to 14 were not done because it was felt that the data desired in those steps could be retrieved from other steps in the program. The purpose of this test was to gather vibration data for the RL10A-3-3A, the hydraulic actuators, and the engine bell plug. This was not a qualification test. This data was used by NASA to fine tune their NASTRAN model analysis, primarily in the 5 to 50 Hz frequency range. Instrumentation consisted of 25 accelerometers and 48 dynamic strain gages, and is listed in Table 2. The pitch and yaw instrumentation designations are in the Centaur configuration, not STS/configuration. The results are reported in the same fashion. Table 3 is a log of maximum level runs for each configuration.

Appendix A contains a photographic record of the instrumentation locations.

The fixture was mounted on the shaker and the first tests were run without the engine to characterize the fixture. The fixture was found to have several resonances in the 5 to 500 Hz range, with strong resonances at 50 and 480 Hz. Because of this, the input control was notched at 50 Hz to keep from overdriving the system. The shaker was controlled by the average of two accelerometers, parameters VGFT and VAPFT. This average was maintained at a constant acceleration level from 500 to 12 Hz and at a constant displacement level from 12 to 5 Hz. All of the data parameters were recorded on MUX tape, with separate tapes for the strain gage data and accelerometer data. Thirty-two of these parameters were also converted to a digital signal and recorded on a computer disk. This enabled these parameters to be processed immediately after each run. Figure 3 shows VGFT, VAPFT as well as other key parameters, the fixture and shaker relative to Shuttle pitch direction and CS 0 (coordinate system zero in the NASA/GDSS NASTRAN model).

There were certain parameters in which NASA was extremely interested. These are listed in Table 4. NASA was supplied with data in three forms: 1) graphs, 2) tables, and 3) tape. Phase data was not supplied because the data recorded on the MUX tapes was at such a low level that the phase processing could not be done. Table 5 is a brief summary of the results for the maximum level in each test configuration. Figures 4 through 7 show load versus input level for several different steps in the test program for key data parameters.

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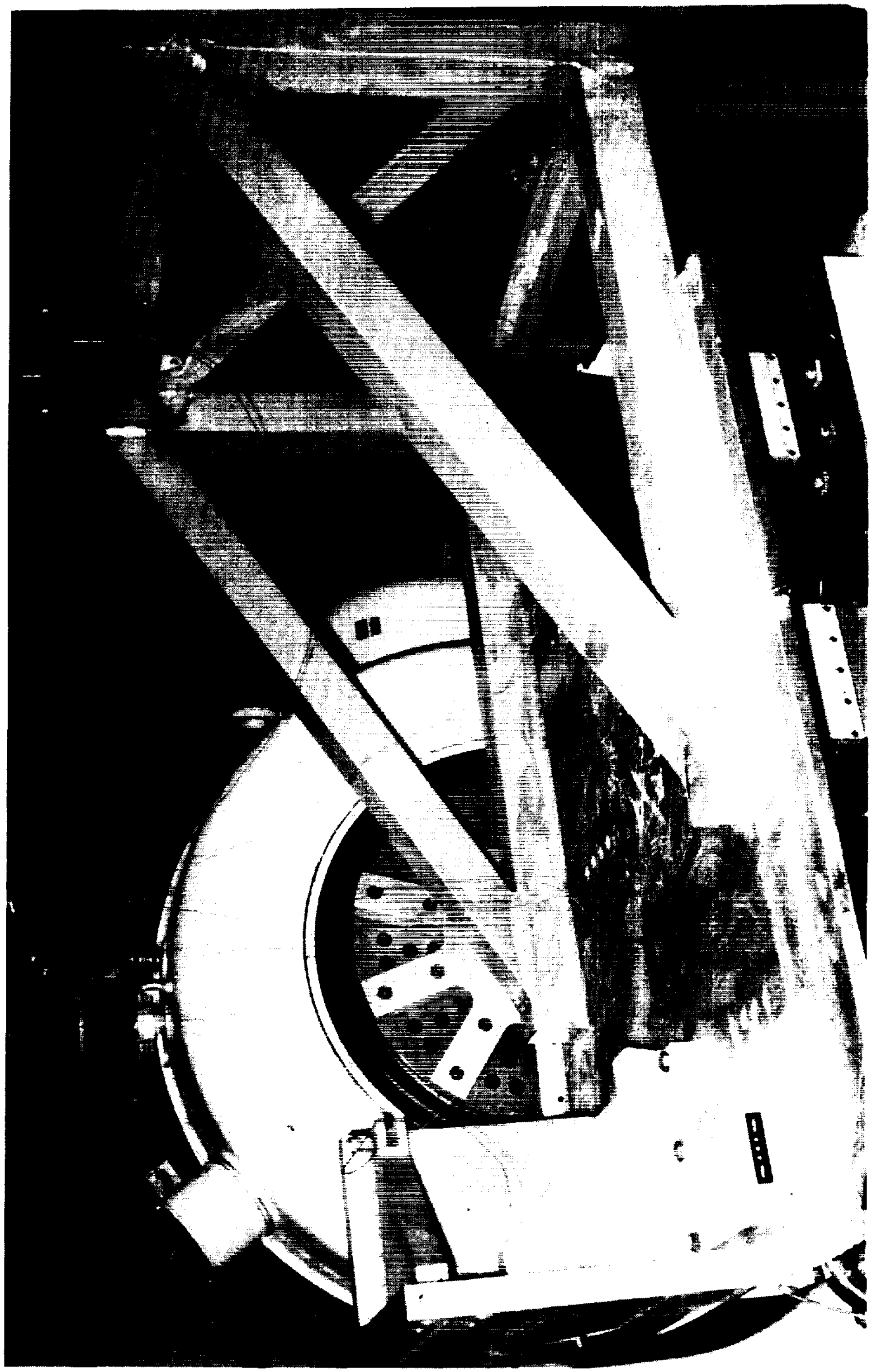

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Figure 1. Engine Test Fixture

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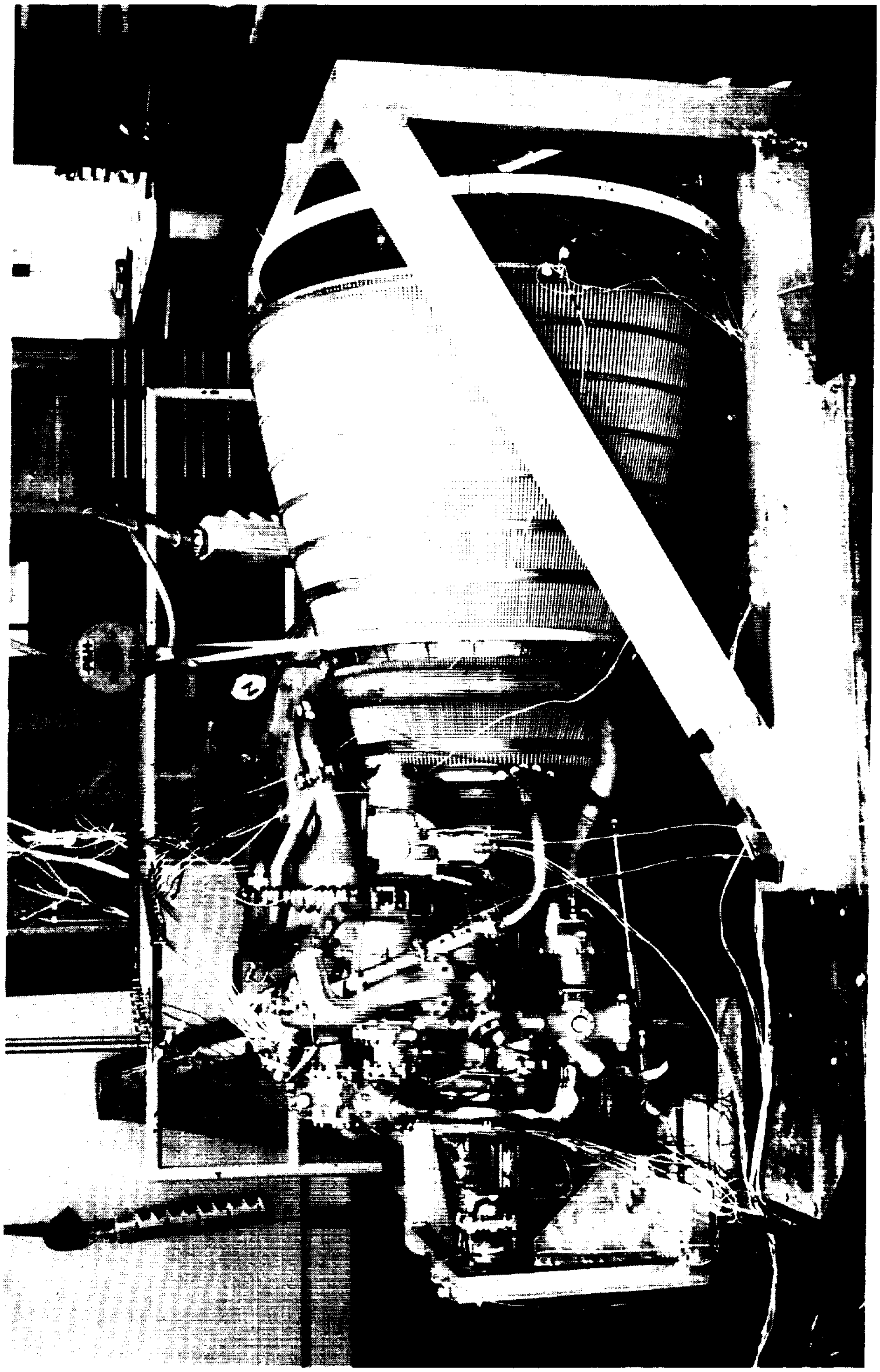

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Figure 2. Engine and Nozzle Support Plug Mounted in Test Fixture

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Table 1. Test Steps and Configurations

Test Number	Actuator Support	Nozzle Support	Comments
1	None	None	No engine, fixture only test. Resonance was found requiring rework.
2	None	None	Retest fixture after rework to verify resonance above 100 Hz.
3	Flight Hydraulics	Yes	Hydraulic system installed on engine. Engine installed in the fixture. Recirculation pump on with a pressure of 110 psi, and servo valves open.
4	Flight Hydraulics	Yes	Same as step 3 except the recirculation pump is off.
5	Solid Rods	Yes	Hydraulic system removed from engine, minimum preload in guided springs of bell support plug.
6	Solid Rods	Yes	Maximum preload in guided springs of bell support plug.
7	None	Yes	Solid rods removed, engine supported at the gimbal and engine bell only.
8	Solid Rods	None	Solid rods reinstalled, bell support plug removed.
9	Flight Hydraulics	None	Pitch actuator locked up or replaced with solid rod bell support plug removed, recirculation pump on, pressure 110 psi, and servo valves open.
10	Flight Hydraulics	None	Same as step 9 with recirculation pump off.
11	None	Yes	Plug only. Mounted in the fixture and excited by a small shaker and a stinger in the vertical direction.
12	None	Yes	Same as step 11 except driven in a diagonal direction in a line with two attachment bolts.
13	Flight Hydraulics	None	Hydraulic system only. Engine removed. Gimbal support block moved to allow one actuator to be driven by big shaker. Recirculation pump on, pressure 110 psi, servo valves open.
14	Flight Hydraulics	None	Actuator test same as step 13 but with recirculation pump off.

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Table 2. STS/Centaur/RL10A-3-3A Engine (XR104) Shaker Test Instrumentation Callout

Parameter No.	*Transducer Type*	*Ident*	*Comments*
1	Accelerometer	VGEA	Engine Side Gimbal Axial
2	Accelerometer	VGER	Engine Side Gimbal Radial
3	Accelerometer	VGET	Engine Side Gimbal Tangential
4	Accelerometer	VGFA	Fixture Side Gimbal Axial
5	Accelerometer	VGFR	Fixture Side Gimbal Radial
6	Accelerometer	VGFT	Fixture Side Gimbal Tangential
7	Accelerometer	VAPEA	Engine Side Pitch Actuator Axial
8	Accelerometer	VAPER	Engine Side Pitch Actuator Radial
9	Accelerometer	VAPET	Engine Side Pitch Actuator Tangential
10	Accelerometer	VAPFA	Fixture Side Pitch Actuator Axial
11	Accelerometer	VAPFR	Fixture Side Pitch Actuator Radial
12	Accelerometer	VAPFT	Fixture Side Pitch Actuator Tangential
13	Accelerometer	VAYEA	Engine Side Yaw Actuator Axial
14	Accelerometer	VAYER	Engine Side Yaw Actuator Radial
15	Accelerometer	VAYET	Engine Side Yaw Actuator Tangential
16	Accelerometer	VAYFA	Fixture Side Yaw Actuator Axial
17	Accelerometer	VAYFR	Fixture Side Yaw Actuator Radial
18	Accelerometer	VAYFT	Fixture Side Yaw Actuator Tangential
19	Accelerometer	VBEYA	Engine Bell Opposite of Yaw Actuator Attachment Axial
20	Accelerometer	VBEYR	Engine Bell Opposite of Yaw Actuator Attachment Radial
21	Accelerometer	VBEYT	Engine Bell Opposite of Yaw Actuator Attachment Tangential
22	Accelerometer	VPEA	Engine Side Bell Plug Axial
23	Accelerometer	VPFA	Fixture Side Bell Plug Axial
24	Accelerometer	VPFR	Fixture Side Bell Plug Radial
25	Accelerometer	VPFT	Fixture Side Bell Plug Tangential
30	Accelerometer	VFPDV	Fuel Pump Discharge Valve
31	Dynamic S.G.	SGEI1	Engine Injector Location 1
32	Dynamic S.G.	SGEI2	Engine Injector Location 2
33	Dynamic S.G.	SGEI3	Engine Injector Location 3
34	Dynamic S.G.	SGEI4	Engine Injector Location 4
35	Dynamic S.G.	SGEI5	Engine Injector Location 5
36	Dynamic S.G.	SGEI6	Engine Injector Location 6
37	Dynamic S.G.	SGEI7	Engine Injector Location 7
38	Dynamic S.G.	SGEM1	Engine Fuel Injector Manifold 1
39	Dynamic S.G.	SGEM2	Engine Fuel Injector Manifold 2
40	Dynamic S.G.	SGEM3	Engine Fuel Injector Manifold 3
41	Dynamic S.G.	SGEDVT	Engine Pump Discharge Valve Tube
42	Dynamic S.G.	SGEMCV	Engine Mixture Ratio Control Valve
43	Dynamic S.G.	SGEOPH1	Engine Oxidizer Pump Housing 1
44	Dynamic S.G.	SGEOPH2	Engine Oxidizer Pump Housing 2
45	Dynamic S.G.	SGEOPH3	Engine Oxidizer Pump Housing 3
46	Dynamic S.G.	SGEJIL	Engine Jacket Inlet Line
47	Dynamic S.G.	SGESVT1	Engine Fuel Shutoff Valve Tube 1
48	Dynamic S.G.	SGESVT2	Engine Fuel Shutoff Valve Tube 2
49	Dynamic S.G.	SGESVT3	Engine Fuel Shutoff Valve Tube 3
50	Dynamic S.G.	SGEPS1	Engine Pump Strut 1
51	Dynamic S.G.	SGEPS2	Engine Pump Strut 2
52	Dynamic S.G.	SGEPS3	Engine Pump Strut 3
53	Dynamic S.G.	SGEPS4	Engine Pump Strut 4
54	Dynamic S.G.	SGEJIF1	Engine Jacket Inlet Flange 1

Table 2. *STS/Centaur/RL10A-3-3A Engine (XR104) Shaker Test Instrumentation Callout (Continued)*

Parameter No.	Transducer Type	Ident	Comments
55	Dynamic S.G.	SGEJIF2	Engine Jacket Inlet Flange 2
56	Dynamic S.G.	SGEJIF3	Engine Jacket Inlet Flange 3
57	Dynamic S.G.	SGEJIF4	Engine Jacket Inlet Flange 4
58	Dynamic S.G.	SGEJIF5	Engine Jacket Inlet Flange 5
59	Dynamic S.G.	SGEJIM1	Engine Jacket Inlet Manifold 1
60	Dynamic S.G.	SGEJIM2	Engine Jacket Inlet Manifold 2
61	Dynamic S.G.	SGEJIM3	Engine Jacket Inlet Manifold 3
62	Dynamic S.G.	SGEJIM4	Engine Jacket Inlet Manifold 4
63	Dynamic S.G.	SGEJIM5	Engine Jacket Inlet Manifold 5
64	Dynamic S.G.	SGEJIM6	Engine Jacket Inlet Manifold 6
65	Dynamic S.G.	SGEJIM7	Engine Jacket Inlet Manifold 7
66	Dynamic S.G.	SGEGP	Engine Gimbal Opposite Pitch Actuator Support
67	Dynamic S.G.	SGEGY	Engine Gimbal Opposite Yaw Actuator Support
68	Dynamic S.G.	SGEBTC	Engine Bell Thrust Chamber
69	Dynamic S.G.	SGEAPL1	Engine Pitch Actuator Lug 1
70	Dynamic S.G.	SGEAPL2	Engine Pitch Actuator Lug 2
71	Dynamic S.G.	SGEAPL3	Engine Pitch Actuator Lug 3
72	Dynamic S.G.	SGEAPL4	Engine Pitch Actuator Lug 4
73	Dynamic S.G.	SGEAYL1	Engine Yaw Actuator Lug 1
74	Dynamic S.G.	SGEAYL2	Engine Yaw Actuator Lug 2
75	Dynamic S.G.	SGEAYL3	Engine Yaw Actuator Lug 3
76	Dynamic S.G.	SGEAYL4	Engine Yaw Actuator Lug 4
77	Dynamic S.G.	SGET1	Engine Throat Maewest 1
78	Dynamic S.G.	SGET2	Engine Throat Maewest
79	Load Cell	LCPA	Pitch Actuator
80	Load Cell	LCYA	Yaw Actuator
81	Load Cell	LCTS	Torque Spool (ZAX1S)
82	Freq Refs		Sweep Oscillator AC and DC Outputs
83	Freq Refs Backup		Sweep Oscillator AC and DC Outputs
84	Accelerometer	VP2FT	Mount Frame Lug Closest Shaker
85	Accelerometer		Avg of Parameters 6 and 18
86	Pres Xducer		Flight Hydraulics Pressure

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Table 3. *RL10A-3-3A Vibration Test Log*

Date	Run No. XR014	Program Test No. per Table 1	Actuator Configuration	Nozzle Support	Actuator Recirculation Pump	Sweep Freq. hz	Shaker Input G Pk/ in. DA	Record Mux Tape No.
5/17/85	18	4	Flight Hydraulics	Yes	Off	500-5	0.8/0.109	SX137025
5/17/85	19	3	Flight Hydraulics	Yes	On	500-5	0/8/0.109	SX137035
5/18/85	25	9	Flight Hydraulics	No	On	500-5	0.75/0.102	SX138035
5/21/85	32	8	Solid Rods	No	NA	500-5	0.40/0.054	SX141035
5/22/85	36	6	Solid Rods	Nominal Preload	NA	500-5	1.0/0.136	SX142035
5/23/85	40	5	Solid Rods	Minimum Preload	NA	500-5	0.75/0.102	SX143015
5/23/85	46	7	None	Nominal Preload	NA	500-5	0.85/0.116	SX143045

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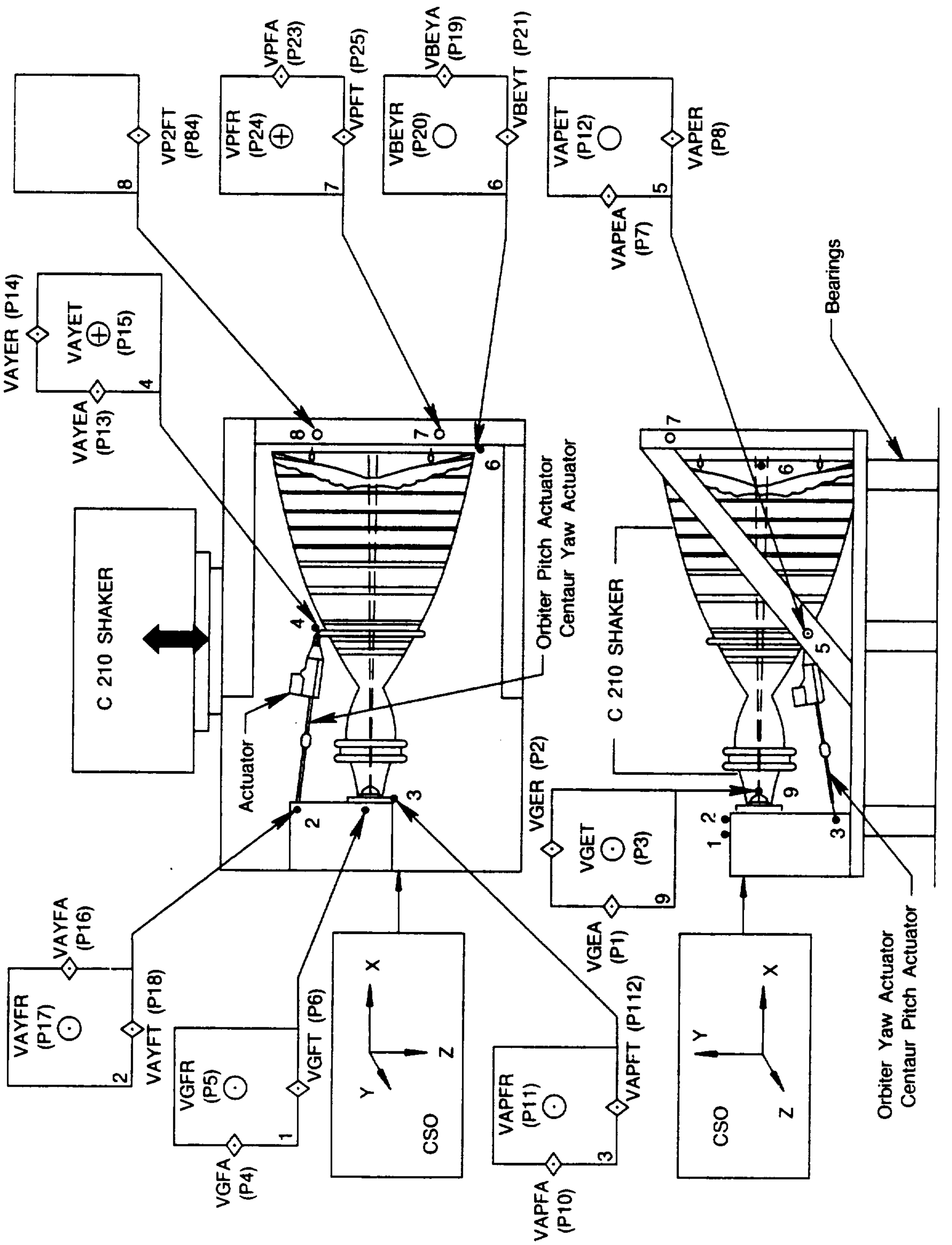

Figure 3. Engine Test Fixture Block Diagram

Table 4. NASA LeRC Priority Instrumentation List

Parameter Number	Parameter Name	Parameter Description
18	VAYFT	Fixture Side Yaw Actuator Tangential
6	VGFT	Fixture Side Gimbal Tangential
25	VPFT	Fixture Side Bell Plug Tangential
12	VAPET	Engine Side Pitch Actuator Tangential
80	YLOAD	Yaw Loadcell
79	PLOAD	Pitch Loadcell
77	SGET1	Engine Throat Maewest
53	SGEPS4	Engine Pump Strut 4
57	SGEJ1F4	Engine Jacket Inlet Flange 4
21	VBEYT	Engine Bell Opposite Yaw Actuator
8	VAPER	Engine Side Pitch Actuator Radial
11	VAPFR	Fixture Side Pitch Actuator Radial
14	VAYER	Engine Side Yaw Actuator Radial
20	VBEYR	Engine Bell Opposite Yaw Actuator

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Table 5. STS/Centaur/RL10A-3-3A (Engine XR-104) Shaker Test Data Summary

Run No.	Test Step No.	Input Exciter Level	Pitch Load lb-Pk	Yaw Load lb-Pk	Maximum Stress Ksi-Pk
18	4	0.8 G Pk	125	100	SG EPS4 = 20.7
19	3	0.8 G Pk	130	225	SG EPS4 = 14.6
25	9	0.75 G Pk	530	720	SGEAYL3 = 26.4
32	8	0.4 G Pk	1000	1500	SGEAYL3 = 22.5
36	6	1.0 G Pk	165	330	SG EPS4 = 36.8
40	5	0.75 G Pk	140	300	SG EPS4 = 28.0
45	7	0.85 G Pk	N/A	N/A	SGEJIF4 = 19.0

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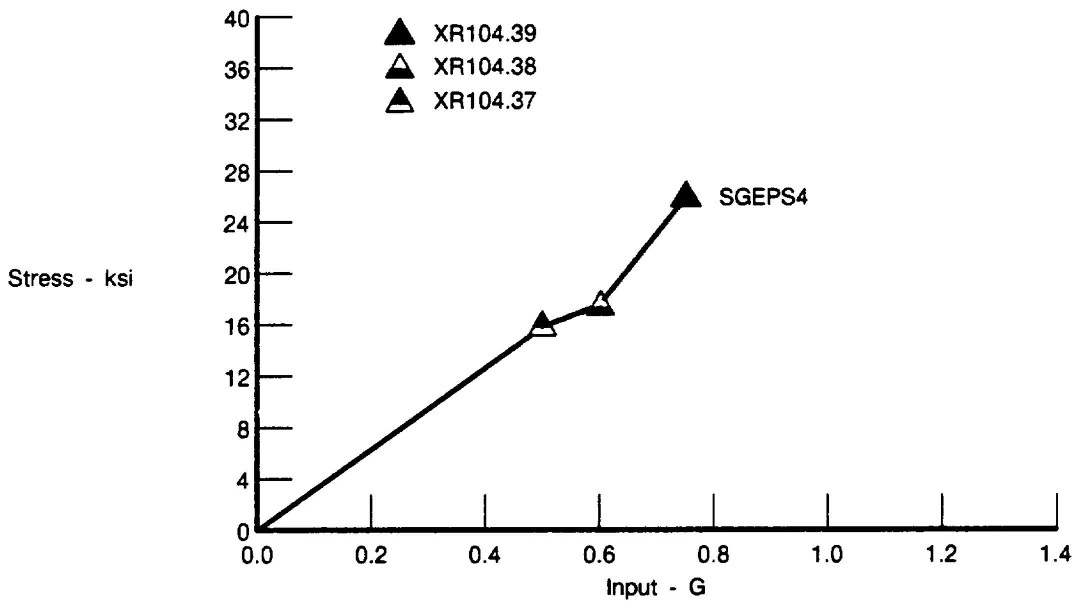

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Figure 4. Load vs Input Level — Test Step 5

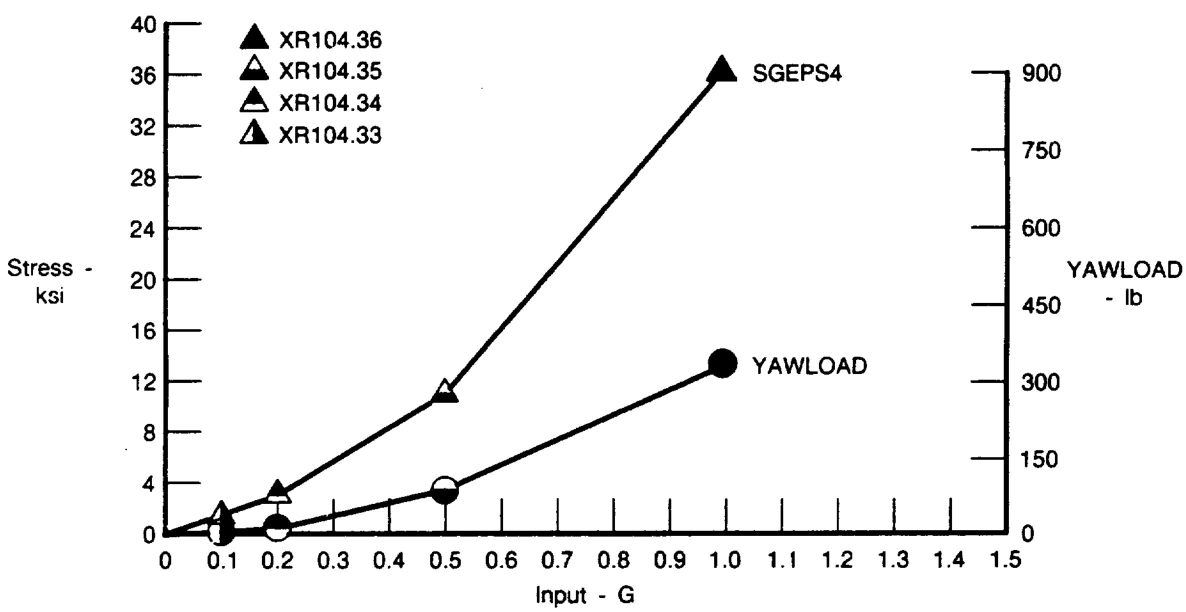

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Figure 5. Load vs Input Level — Test Step 6

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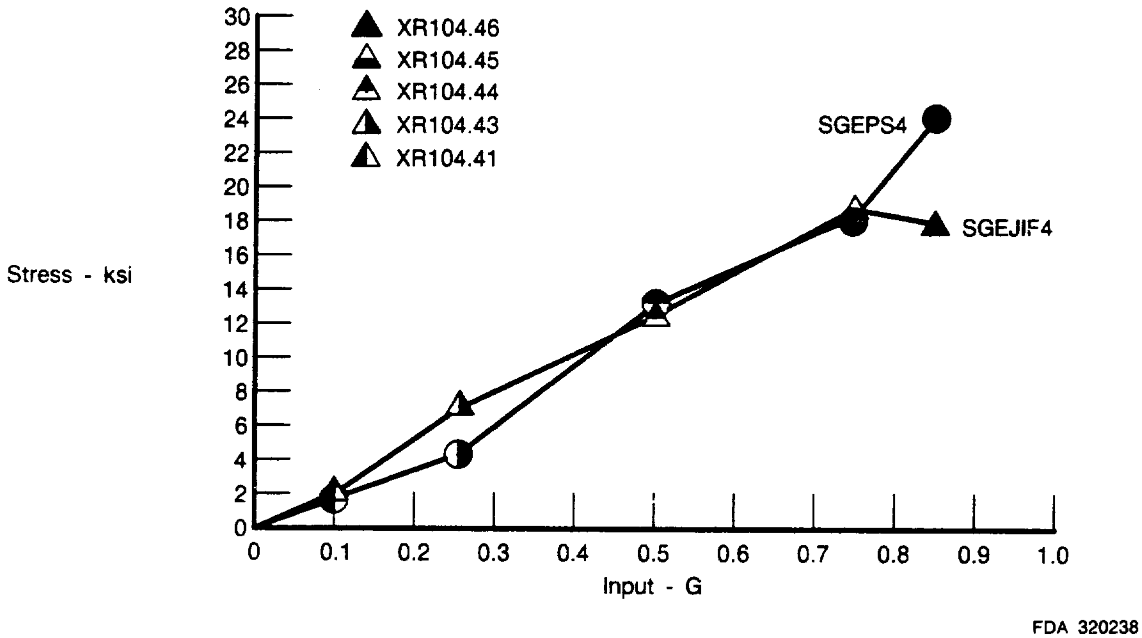

Figure 6. Load vs Input Level — Test Step 7

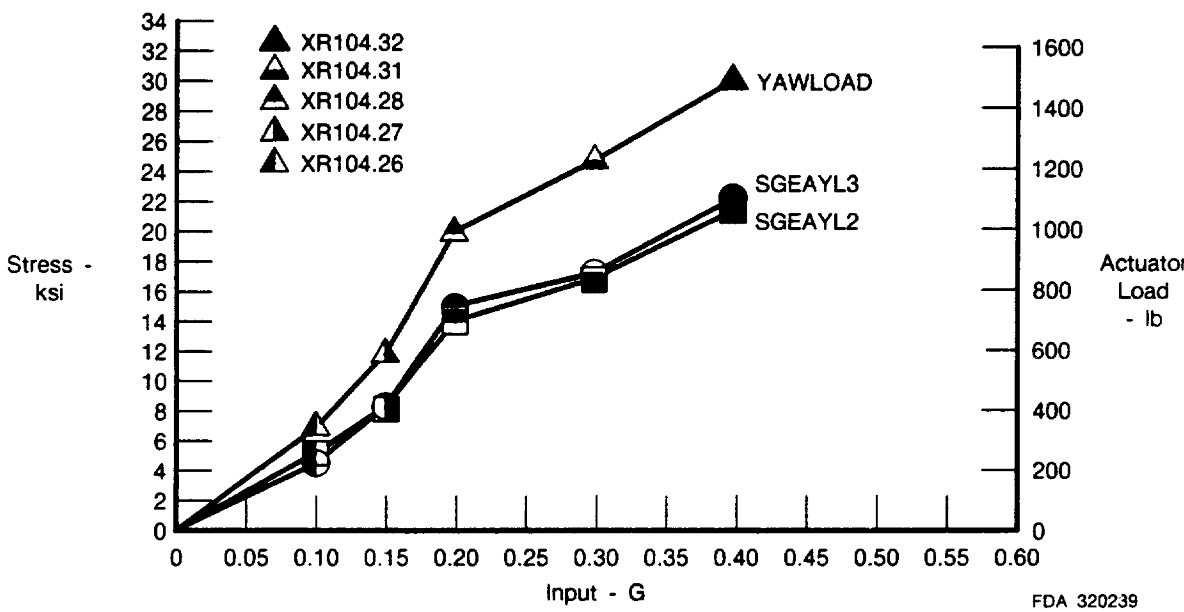

Figure 7. Load vs Input Level — Test Step 8

During testing it was noticed that locking nuts for the bell support plug were coming loose. A fix was developed for this problem that required the self locking nuts to be replaced with nuts that were secured with safety wire. In subsequent testing, the nuts showed no signs of coming loose. The bell support plug also showed signs of wear. This wear was evident on the Teflon seal in the form of blackened burnished marks and pits. This was after approximately nine hours of testing and certainly would not have been a problem during actual use at similar test levels.

NASA review of the data concluded that the testing P&W had done was more severe than the STS/Centaur environment. Therefore no qualification test was required for the sine portion of the vibration specification.

When the NASA/GDSS model was reanalyzed using the data gathered during this test, engine stresses and actuator loads were well within the limits of the RL10 specification.

SECTION 3.0
PHASE II - RANDOM MOTION VIBRATION TEST

Development engine XR105-3 was built as an RL10A-3-3A for testing in October 1985. This engine was configured for hot firing. The engine gimbal was one which had stress corrosion cracks like those recently causing concern, see Figures 8, 9 and 10. The cracks were observed for any further propagation during the vibration test. The engine was mounted in E-6 test stand and fired for 430 seconds. The engine was returned to the assembly floor, verified to be free of leaks, and sent to the vibration lab.

The engine and nozzle support plug were to be mounted in the same fixture used for the RL10A-3-3A sine test. The fixture was originally designed for excitation in the Shuttle pitch direction and had to be modified to allow the engine to be excited in the shuttle yaw and axial planes.

The forward mount was remachined allowing the engine to be rotated 90 degrees to the yaw position, Figure 11. The fixture and slip table were reworked to allow the entire fixture to be rotated to the axial position, Figure 12.

The test consisted of random excitation over a frequency range of 50 to 2000 Hz for three minutes per axis, in accordance with the Power Spectral Density provided by NASA-LeRC, as shown in Figure 13. Instrumentation consisted of 12 strain gages and 12 accelerometers, as shown in Table 6. To be consistent with the RL10A-3-3A sine test, the pitch and yaw directions refer to the Centaur coordinate system and not the STS coordinate system. Appendix B contains figures which show the instrumentation locations.

The data was recorded on two 14-track tape decks for the strain gage data and one for the accelerometer data. This was done to eliminate any "crosstalk" problems that can arise when recording both strain gage data and accelerometer data in the same tape deck.

Before the test was begun the fixture alone was sine swept up to 2000 Hz, at 0.2g input level, to look for extreme fixture resonances in the range from 500 to 2000 Hz. Fixture resonances in the 5 to 500 Hz range were known from the RL10A-3-3A sine test. Figures 14 and 15 are a sample of the data recorded. There were several fixture resonances in the upper frequency range which indicated a possibility of control problems in these areas.

During testing the feedback signal used for controlling the shaker was the accelerometer on the fixture at the gimbal attachment, in the direction of shaker input. The input level to the shaker started out low, at approximately −20 db, and increased in steps to the level called for by NASA. The testing was usually stopped on at least one of the intermediate steps to allow the data tapes to be processed so the results up to that point could be reviewed. Figures 16 through 23 are samples of the processed recorded data.

The maximum stress response in each of the three planes occurred on the turbopump support strut. The response of the other gages showed levels well below the level of the pump strut gage. In the pitch and yaw planes, the input level requested by NASA was either met or exceeded without having to modify it in any way. In the axial plane, the slope of the PSD supplied by NASA had to be modified in the 50 to 120 Hz range, because the controller was having trouble maintaining the proper level in this range. Before the slope was modified, low level excitation predicted stress levels on the pump strut at 150 percent of the fatigue strength at full level. The modified slope was discussed with NASA (Dr. A. Karchmer) and agreed upon.

Figure 24, which is for yaw plane excitation, shows that for frequencies below 100 Hz, the response level drops off as the frequency goes down, as per the NASA supplied PSD. Figure 25, which is for excitation in the axial plane, shows that below 100 Hz the response level doesn't drop off as expected. Figure 26 is for axial excitation with the modified slope. The response level starts falling off around 120 Hz which is where the modifications to the PSD begin. Overall response called for by the unmodified PSD is 5.86 g; with the modified slope the overall response was 5.42 g. This indicates that the overall response level was reduced very little, while successfully quieting the peaks caused by the controller. See Figure 27 for a comparison of the original level and the level with the modified slope. Table 7 is a log of the maximum level events and the maximum response during each.

A review of the test data reveals the following:

- The first 45 seconds of testing in the STS pitch direction were in excess of the proposed PSD levels and produced stresses in the 30 ksi range.
- The remaining 135 seconds, run at the proper levels, produced stresses in the 15 ksi range.
- Stresses during the STS yaw excitation were in the 10 ksi range.
- Due to a problem with the controller, the slope of the proposed PSD was modified in the 50 to 120 Hz range for the STS axial excitation. Stresses during this portion of the test were in the 20 ksi range.

Based on the above observations the RL10A-3-3A would survive the proposed random vibration environment.

The engine was removed from the vibration lab and delivered to the RL10 assembly floor. The engine was Zyglo and visually inspected for any signs of damage that may have been caused by the vibration test. None was found. The gimbal cracks were examined and found to be unchanged. The engine was sent to test and mounted in E-6 test stand. A very small "fuzz" leak was found where the venturi tube attaches to the turbine housing. The leak was judged to be too small to affect engine operation, however the gasket was replaced for test stand safety.

The engine was run for 360 seconds to obtain performance data similar to the previous test. Comparison of the two tests showed engine operation within expected limits. The engine was judged to be capable of proper operation after being subjected to the orbiter payload bay liftoff and ascent environment.

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Figure 8. Engine Gimbal Stress Corrosion Cracks

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Figure 9. Engine Gimbal Stress Corrosion Cracks

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Figure 10. Engine Gimbal Stress Corrosion Cracks

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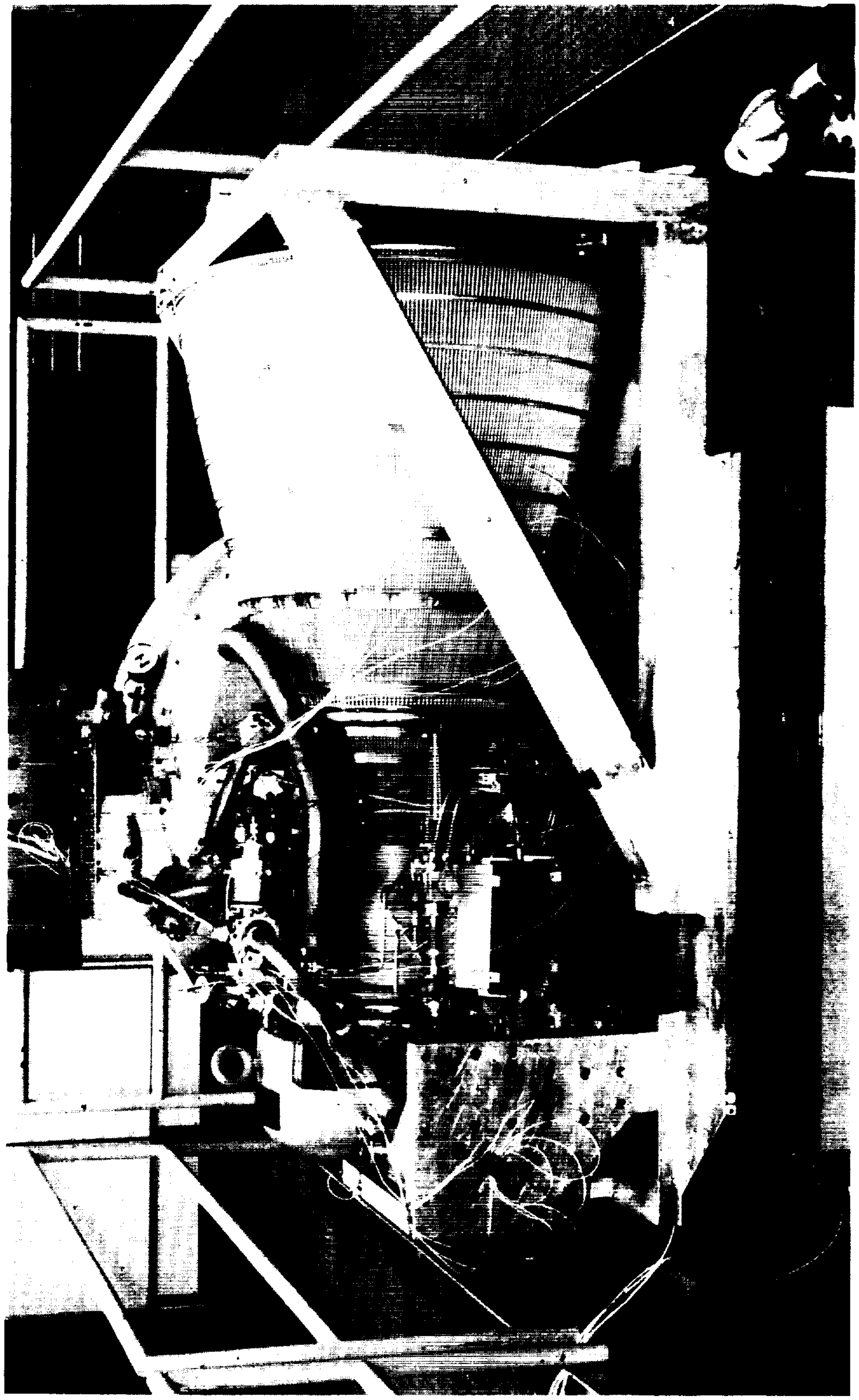

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Figure 11. Engine Rotated 90 Degrees to Yaw Position

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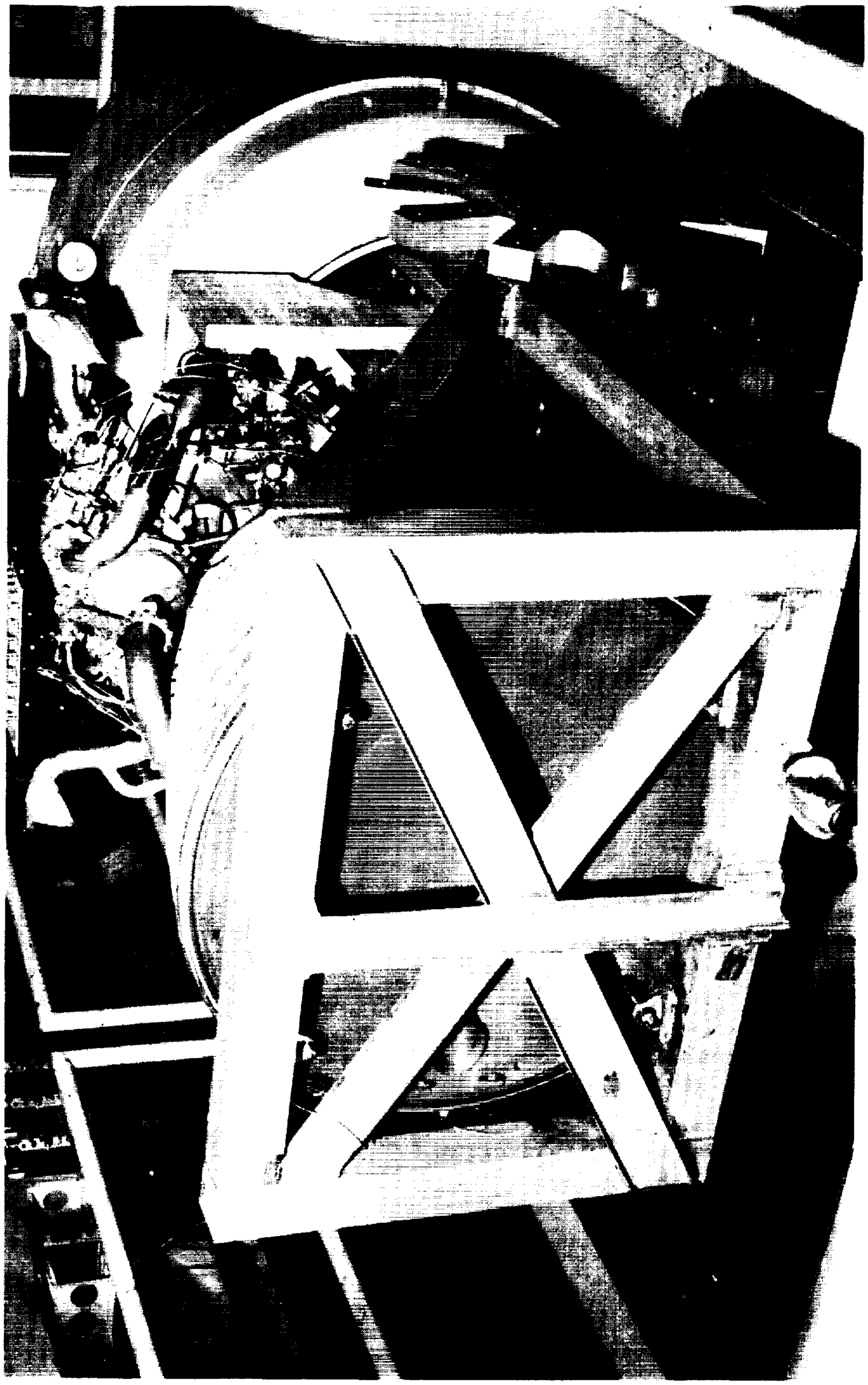

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Figure 12. Engine Rotated to Axial Position

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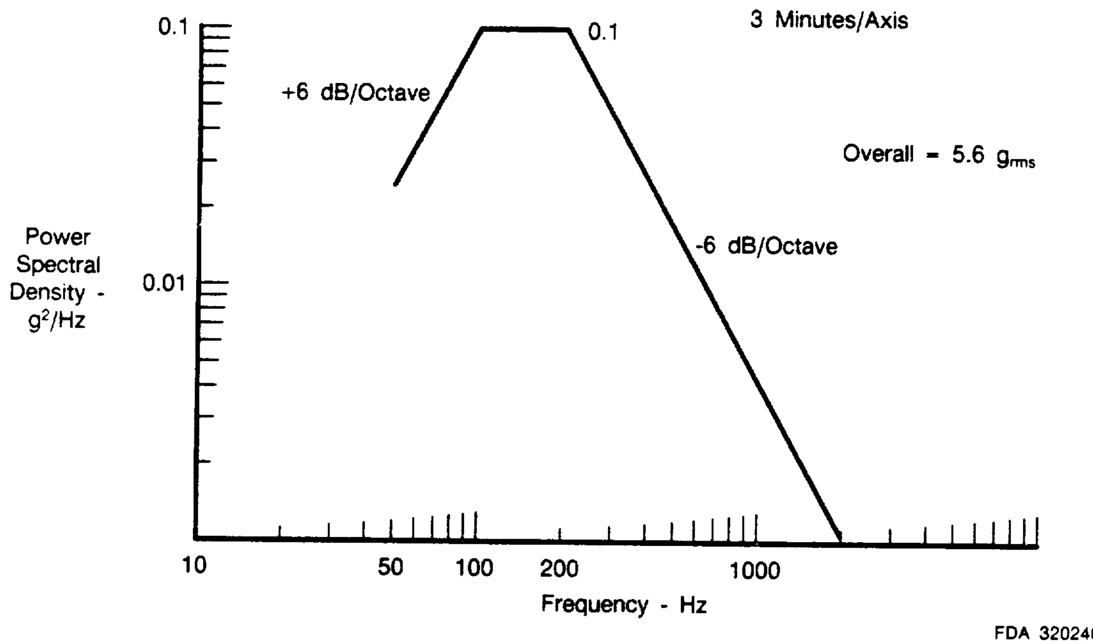

Figure 13. Random Motion Level — Power Spectral Density

Table 6. *RL10 Dynamic Instrumentation Callout*

Device	*Gage Name*	*Installation Figure (Appendix B)*	*Parameter Number*	*Track*	*Comments*
Accelerometer	VGFR	1	P1	1	Fixture Side Gimbal Radial
Accelerometer	VGFT	1	P2	2	Fixture Side Gimbal Tangential
Accelerometer	VGFA	1	P3	3	Fixture Side Gimbal Axial
Accelerometer	VAYER	2	P4	4	Engine Side Yaw Actuator Radial
Accelerometer	VAYET	2	P5	5	Engine Side Yaw Actuator Tangential
Accelerometer	VAYEA	2	P6	6	Engine Side Yaw Actuator Axial
Accelerometer	VBEYR	3	P7	7	Engine Bell Opposite Yaw Actuator Radial
Accelerometer	VBEYT	3	P8	8	Engine Bell Opposite Yaw Actuator Tangential
Accelerometer	VBEYA	3	P9	9	Engine Bell Opposite Yaw Actuator Yaw
Accelerometer	VPFR	3	P10	10	Fixture Side Bell Plug Radial
Accelerometer	VPFT	3	P11	11	Fixture Side Bell Plug Tangential
Accelerometer	VPFA	3	P12	12	Fixture Side Bell Plug Axial
	TIMECODE		P13	13	
Straingage	SGEPS4	4	P15	1	Engine Pump Strut 4
Straingage	SGESVT2	5	P16	2	Engine Fuel Shutoff Tube 2
Straingage	SGEI5	6	P17	3	Engine Injector Location 5
Straingage	SGEJIF4	7	P18	4	Engine Jacket Inlet Flange 4
Straingage	SGEJIF5	7	P19	5	Engine Jacket Inlet Flange 5
Straingage	SGEAPL2	8	P20	6	Pitch Actuator Lug 2
Straingage	SGEAPL3	8	P21	7	Pitch Actuator Lug 3
Straingage	SGEAYL2	2	P22	8	Yaw Actuator Lug 2
Straingage	SGEAYL3	2	P23	9	Yaw Actuator Lug 3
Straingage	SGET1	9	P24	10	Engine Throat 1
Loadcell	PITCHLOAD		P25	11	Pitch Load Cell
Loadcell	YAWLOAD		P26	12	Yaw Load Cell
	TIMECODE		P27	13	
Loadcell	TORQUE		P28	14	Torque Load Cell

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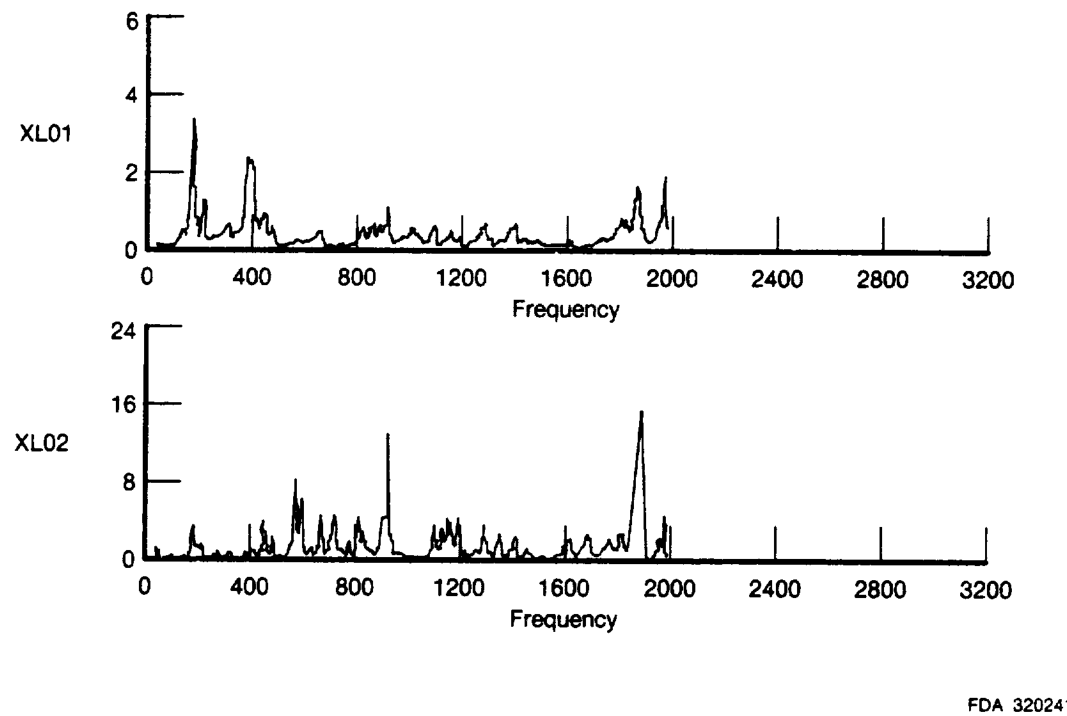

Figure 14. Sample Data Record

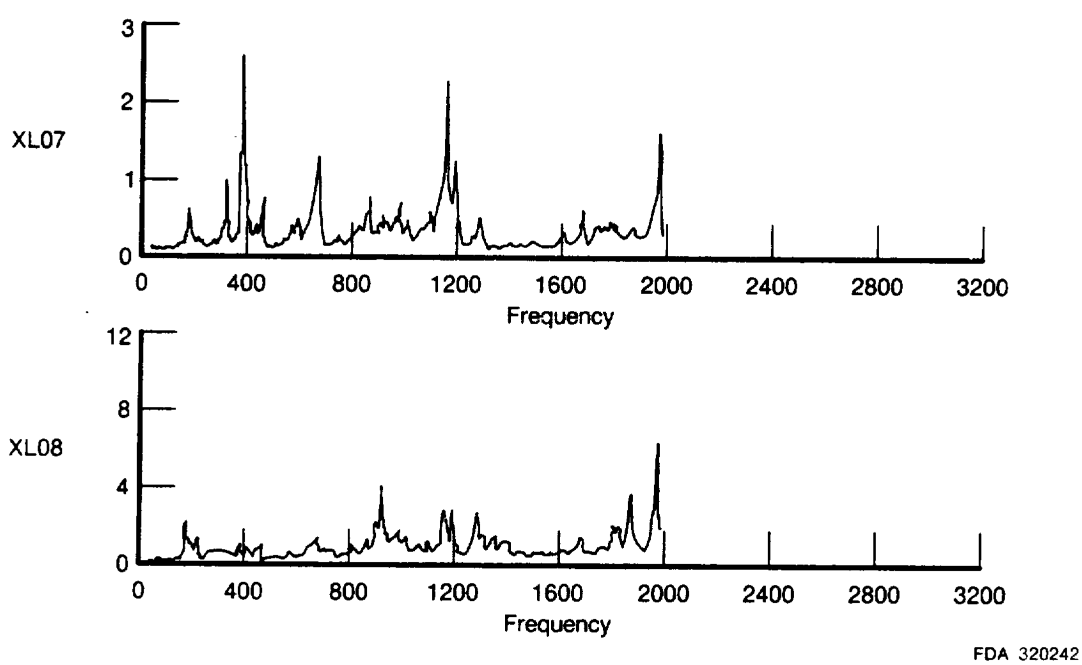

Figure 15. Sample Data Record

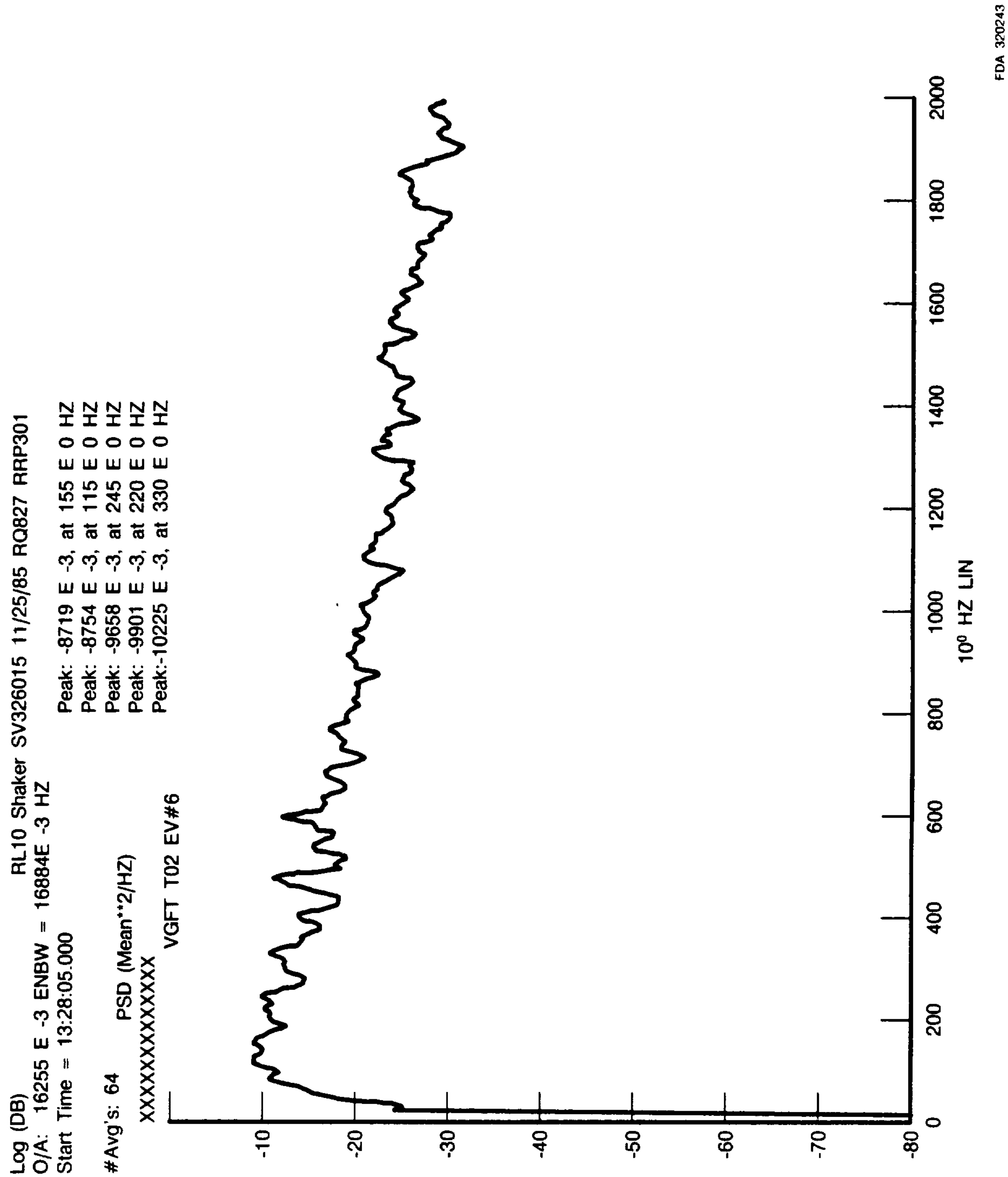

Figure 16. Sample Processed Recorded Data

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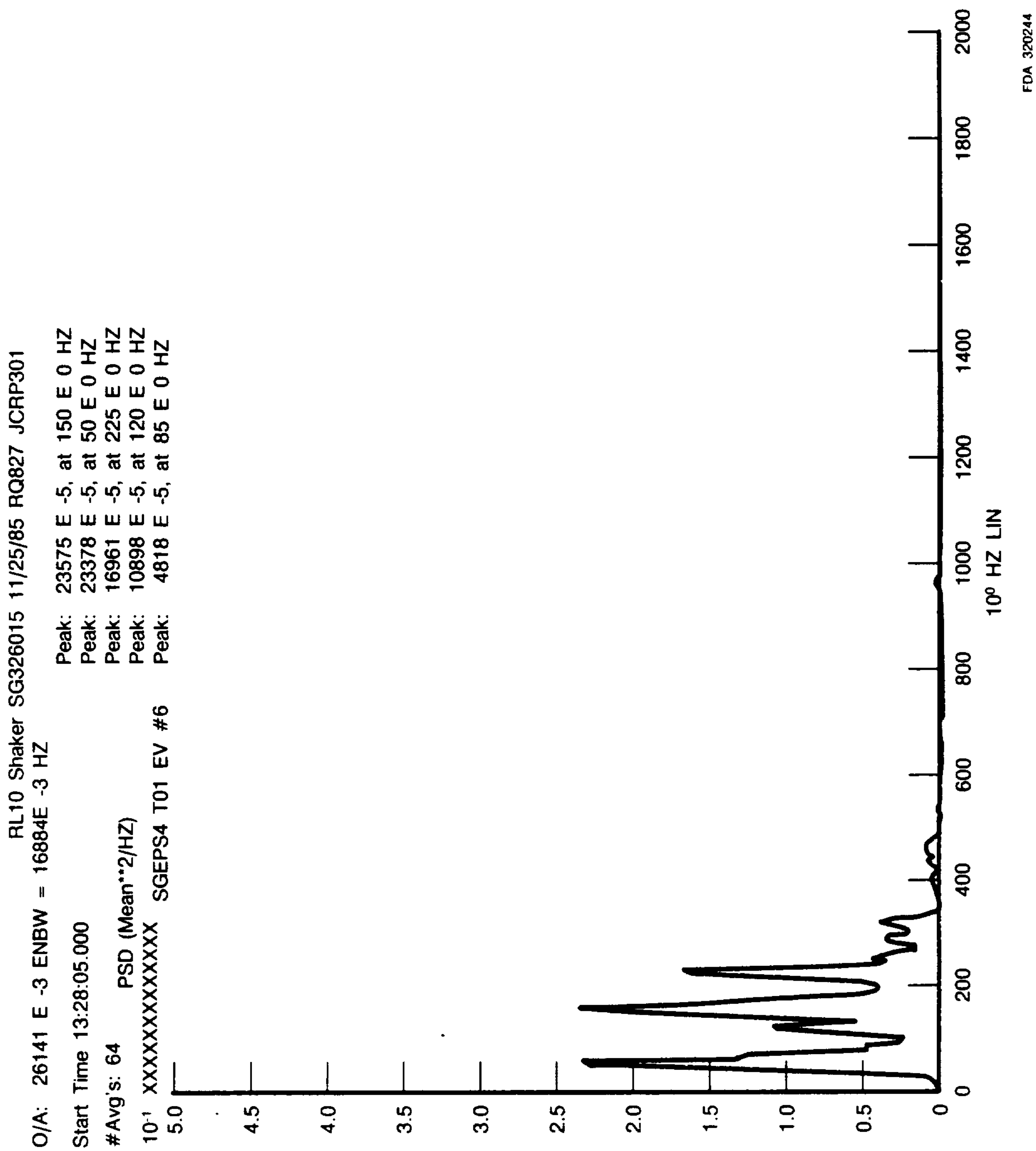

Figure 17. Sample Processed Recorded Data

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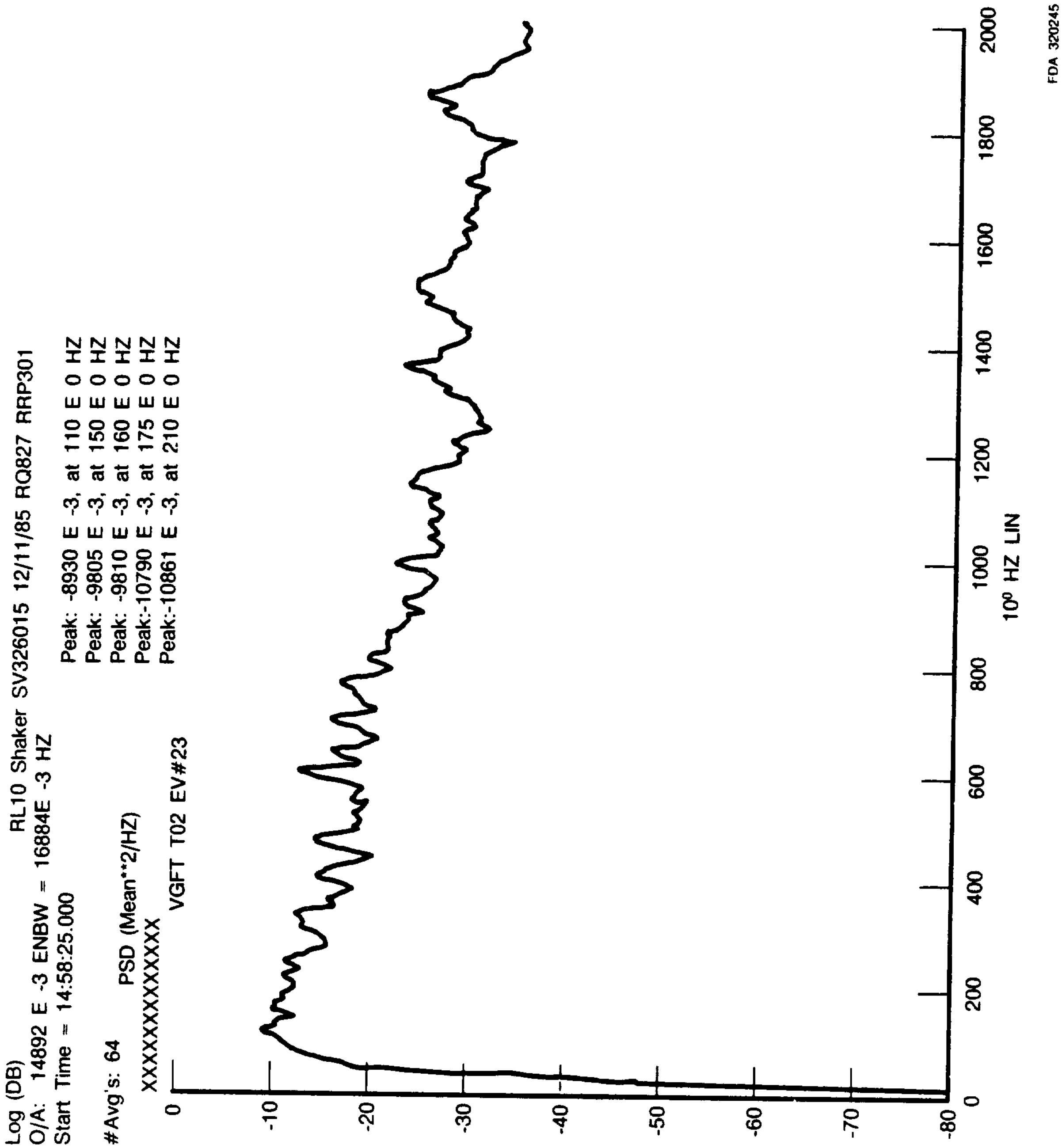

Figure 18. Sample Processed Recorded Data

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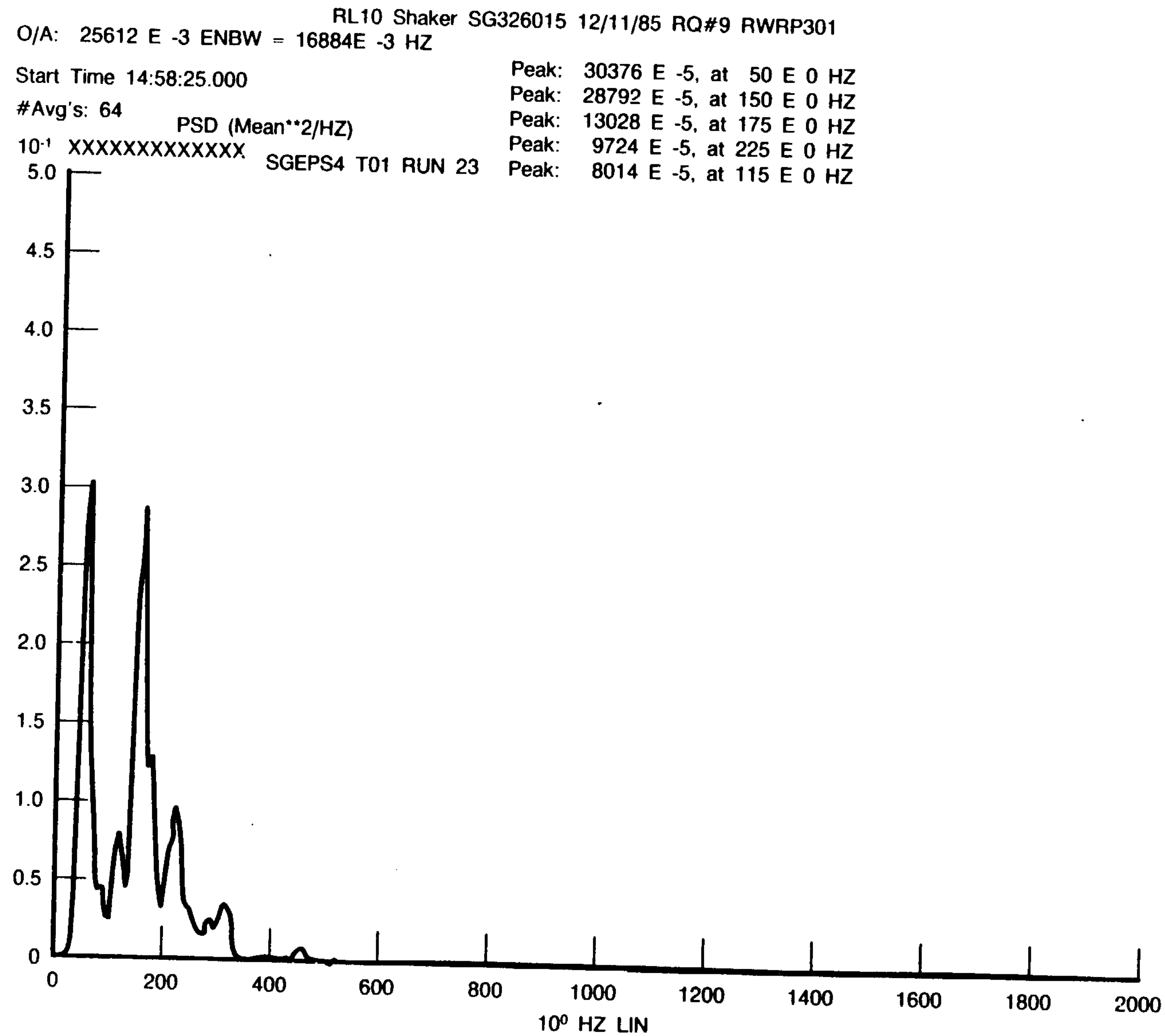

Figure 19. Sample Processed Recorded Data

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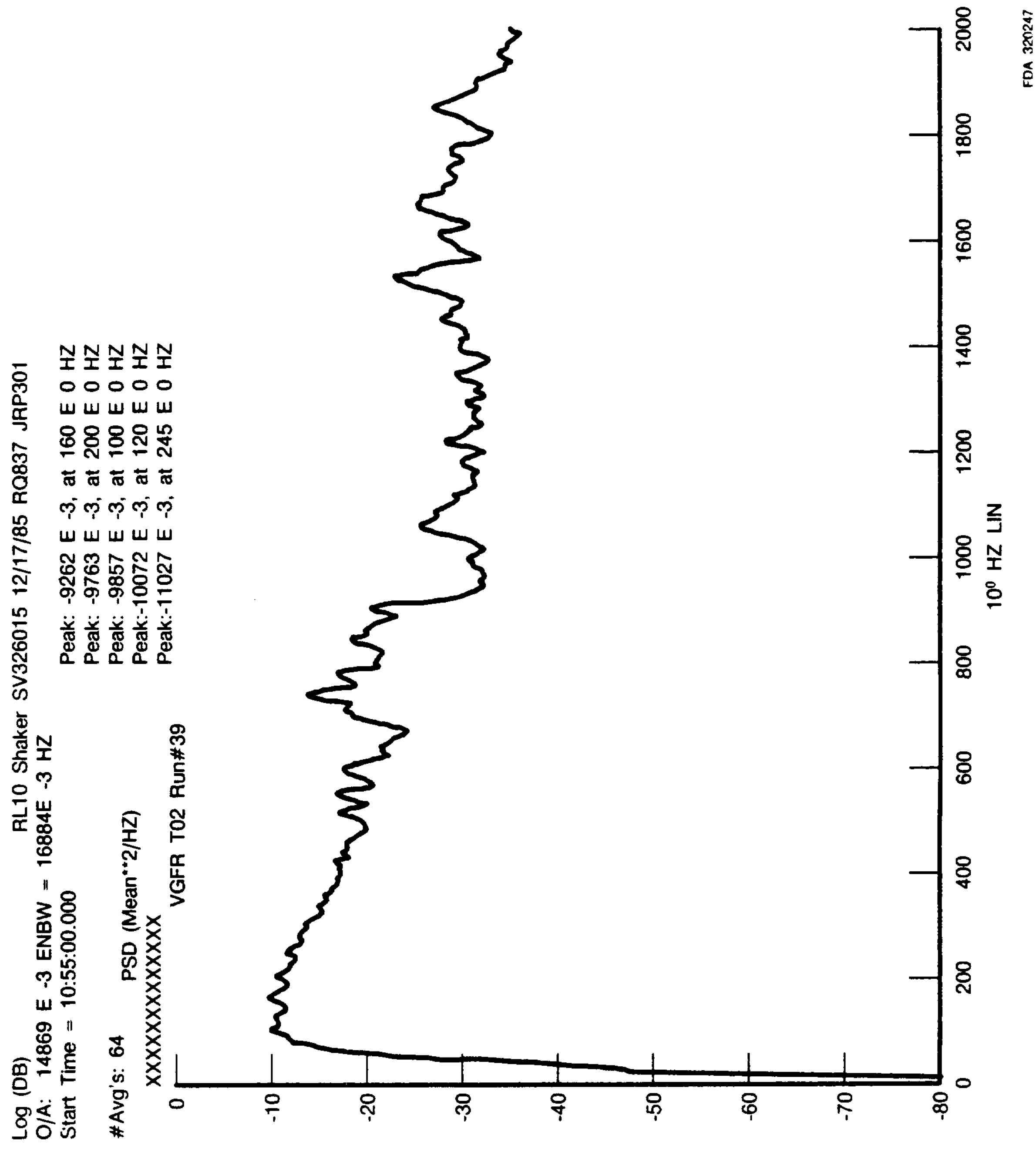

Figure 20. Sample Processed Recorded Data

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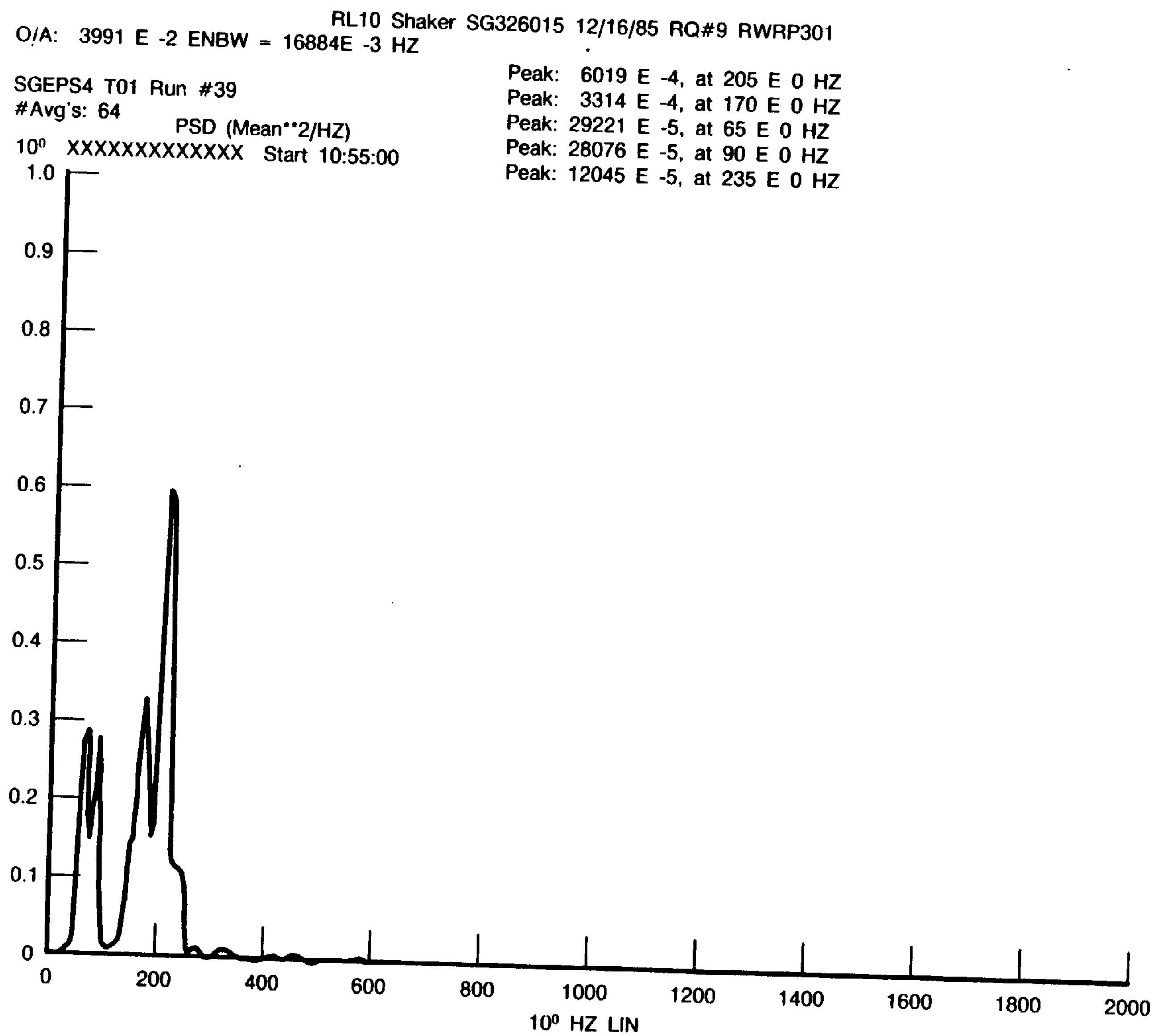

Figure 21. Sample Processed Recorded Data

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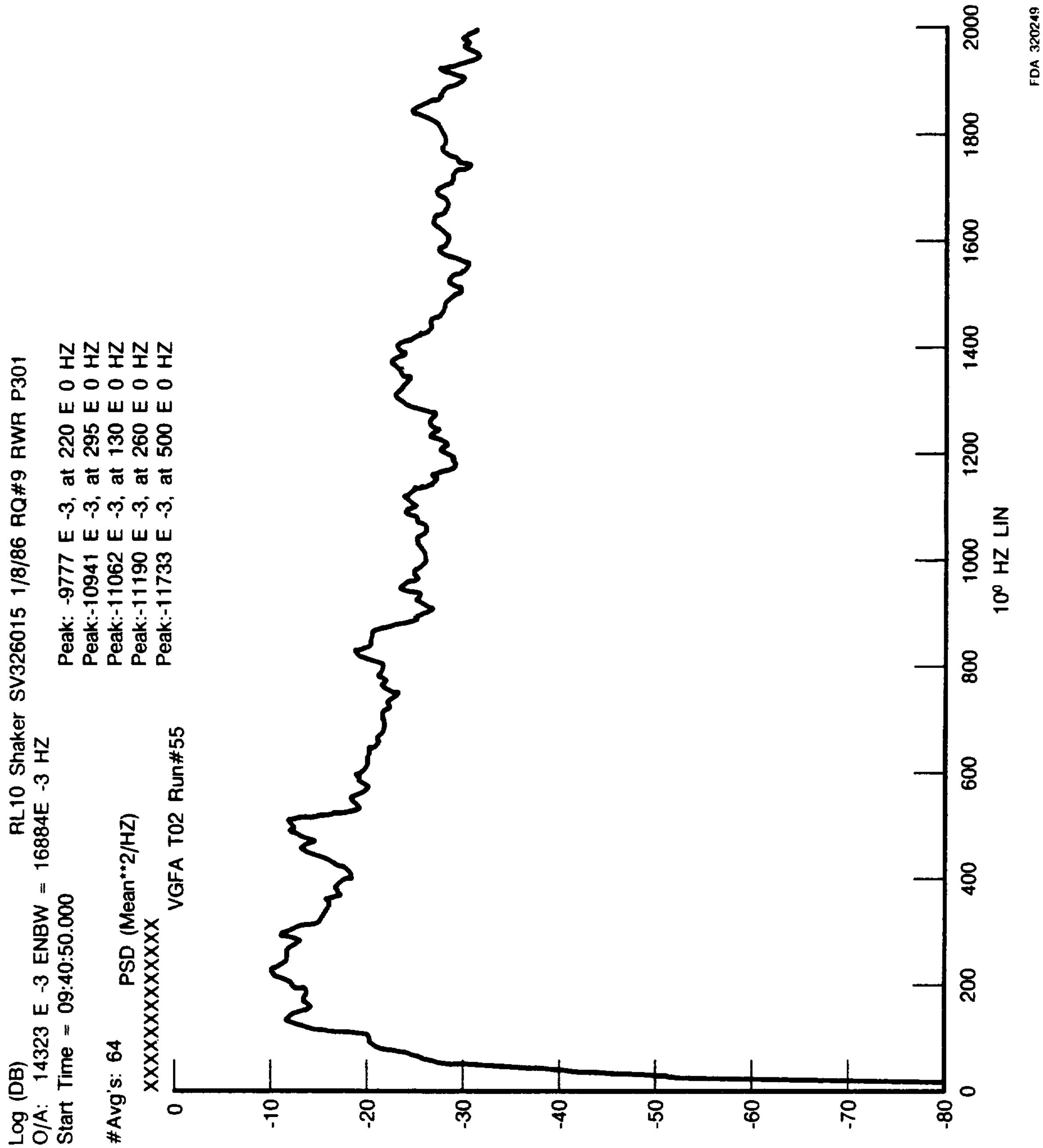

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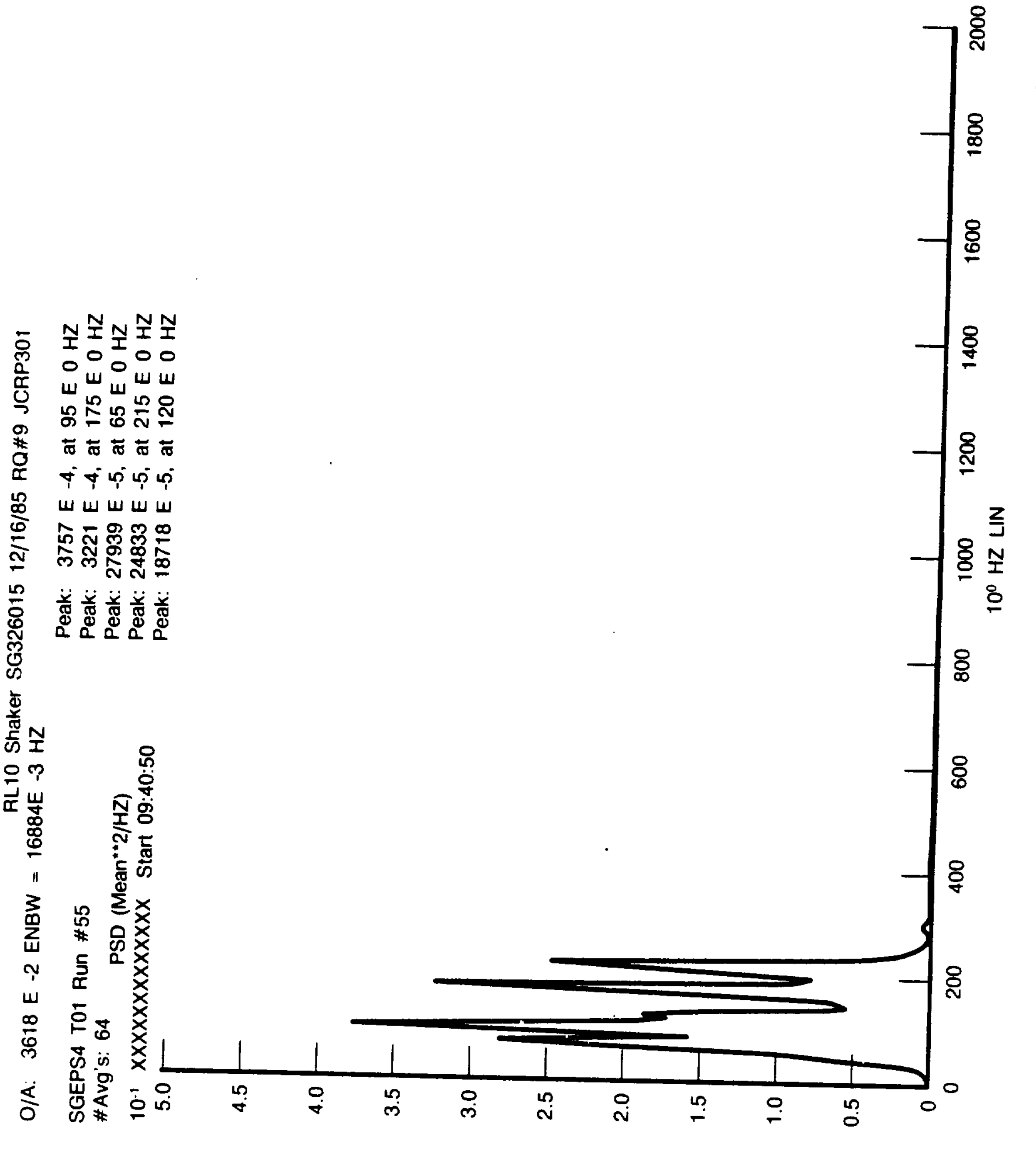

Figure 23. Sample Processed Recorded Data

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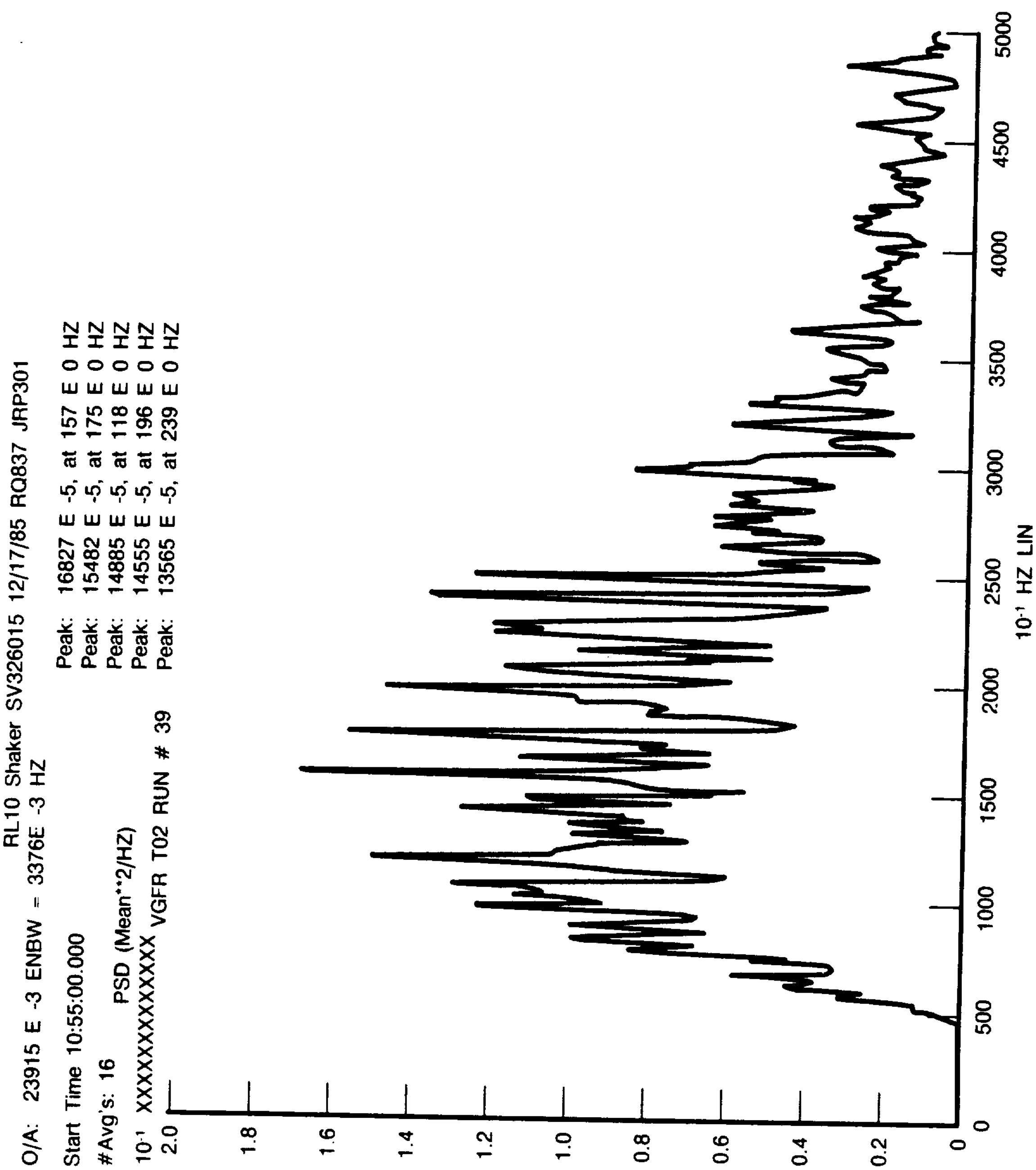

Figure 24. Yaw Plane Excitation

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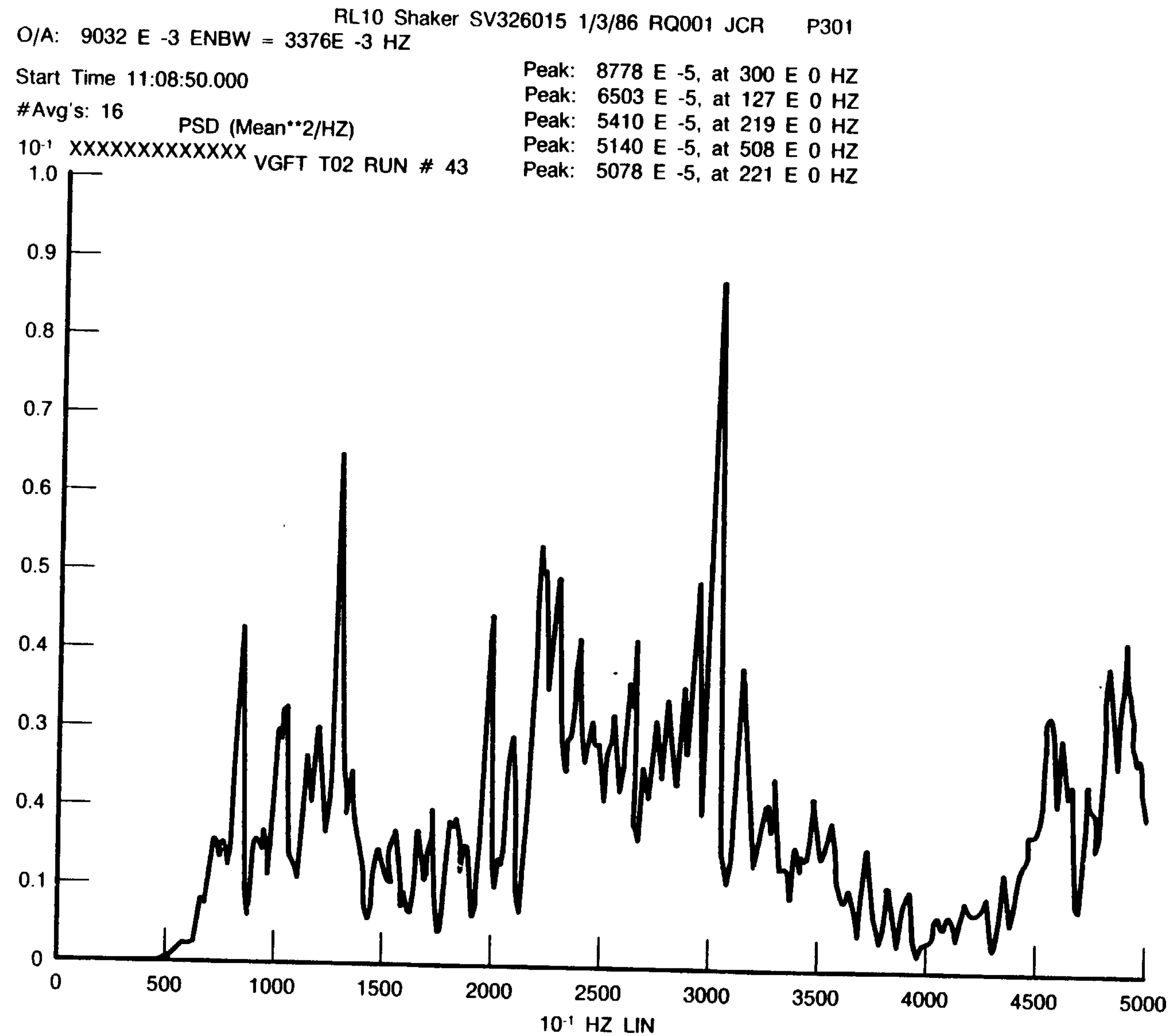

Figure 25. Axial Plane Excitation

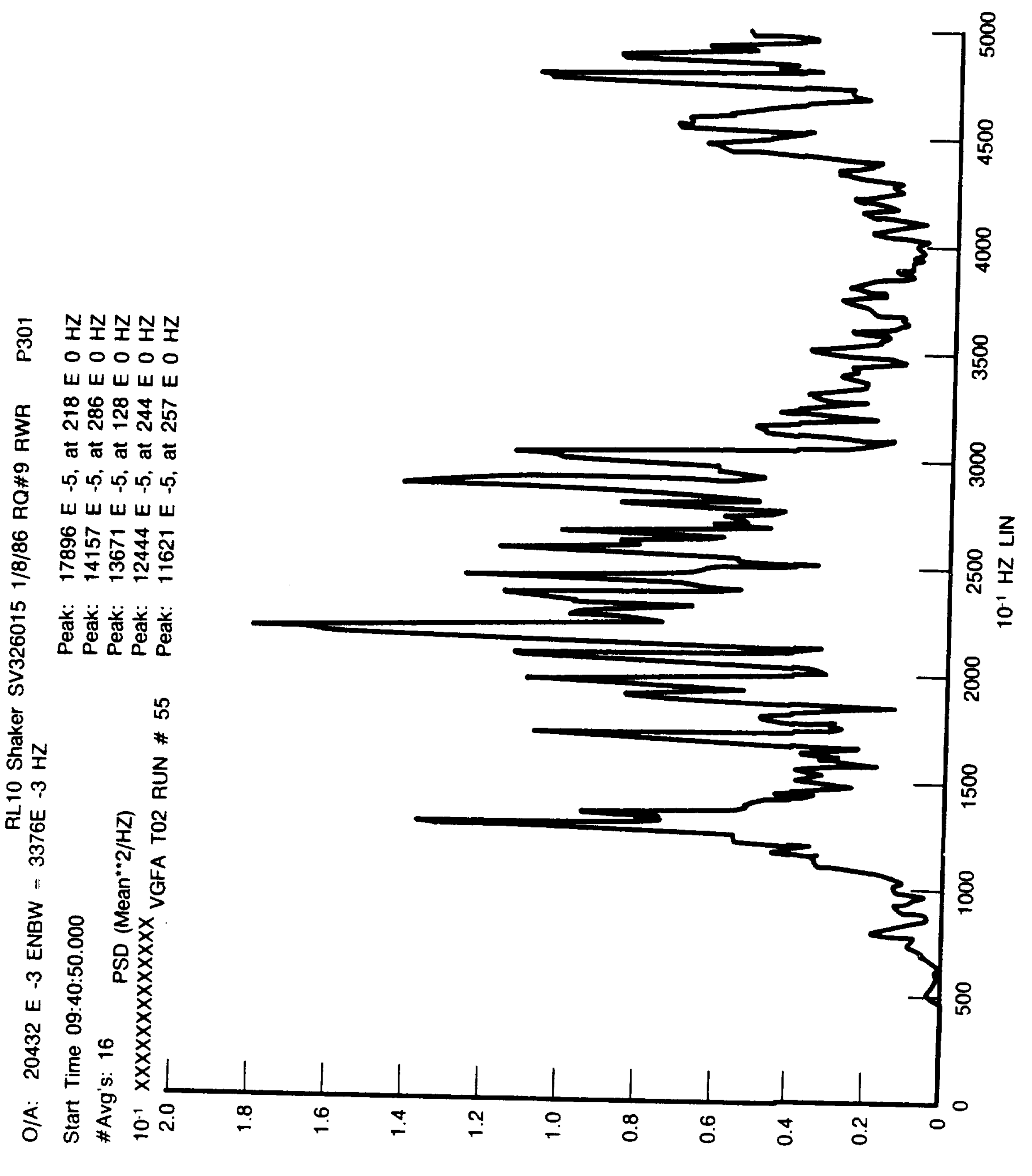

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Figure 26. Axial Plane Excitation With Modified Slope

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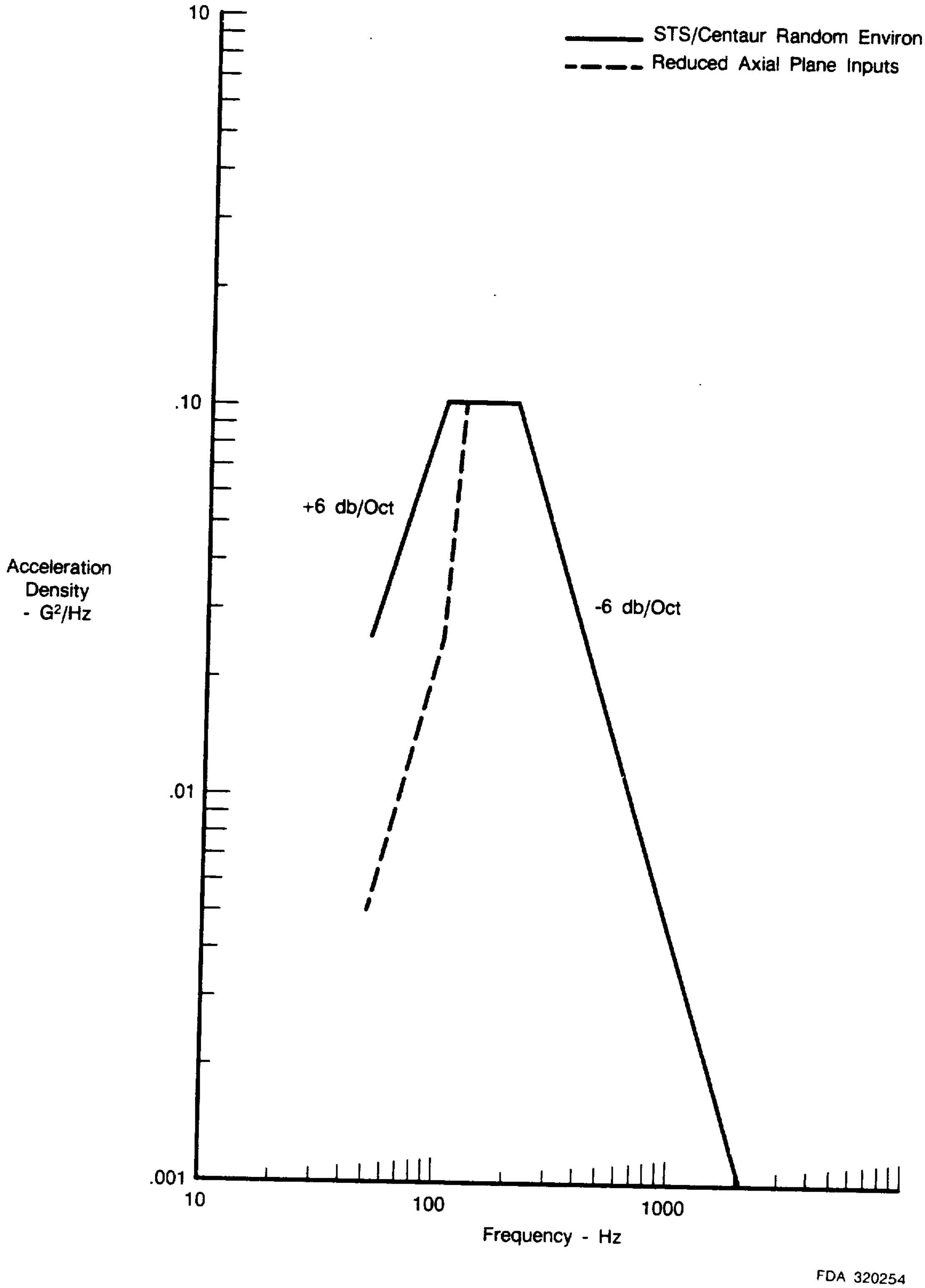

Figure 27. Original Response Level Compared With Modified Slope Level

Table 7. Maximum Level Events

Event Number	Date	Duration (sec)	in G Overall rms	Filter Notch	3 Clipping	Maximum Strain Gage	Stress rms ksi	Excitation Axis
6	11/25/85	45	0db	N	Y	9.75	29.25	STS Pitch
23	12/11/85	135	0db	N	N	5.05	15.15	STS Pitch
39	12/16/85	180	0db	N	N	3.26	9.78	STS Yaw
55	01/08/86	180	0db	MS*	N	6.06	18.18	STS Axial

*Modified Slope

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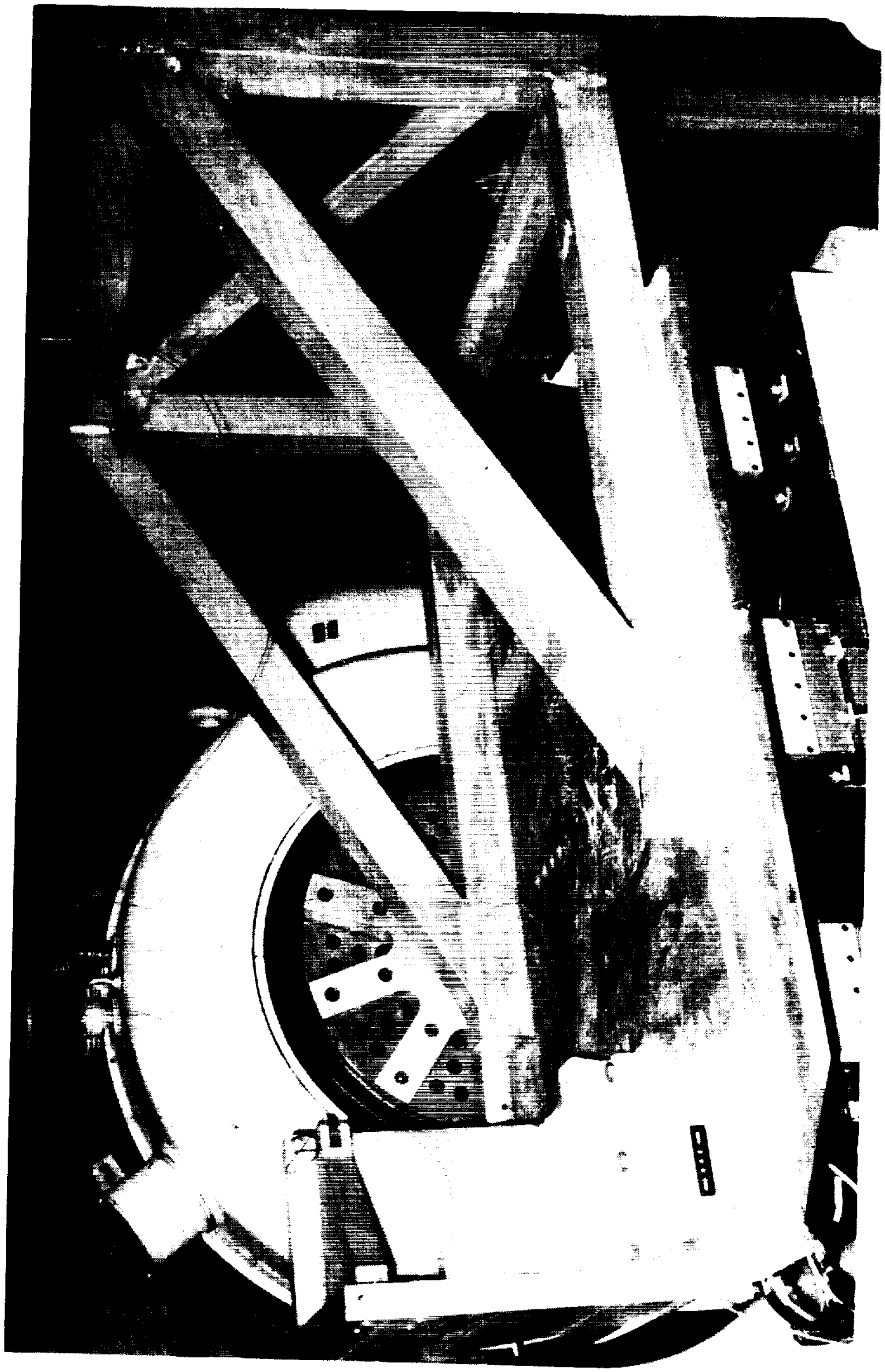
APPENDIX A
TEST SET-UP INSTRUMENTATION PHOTOS



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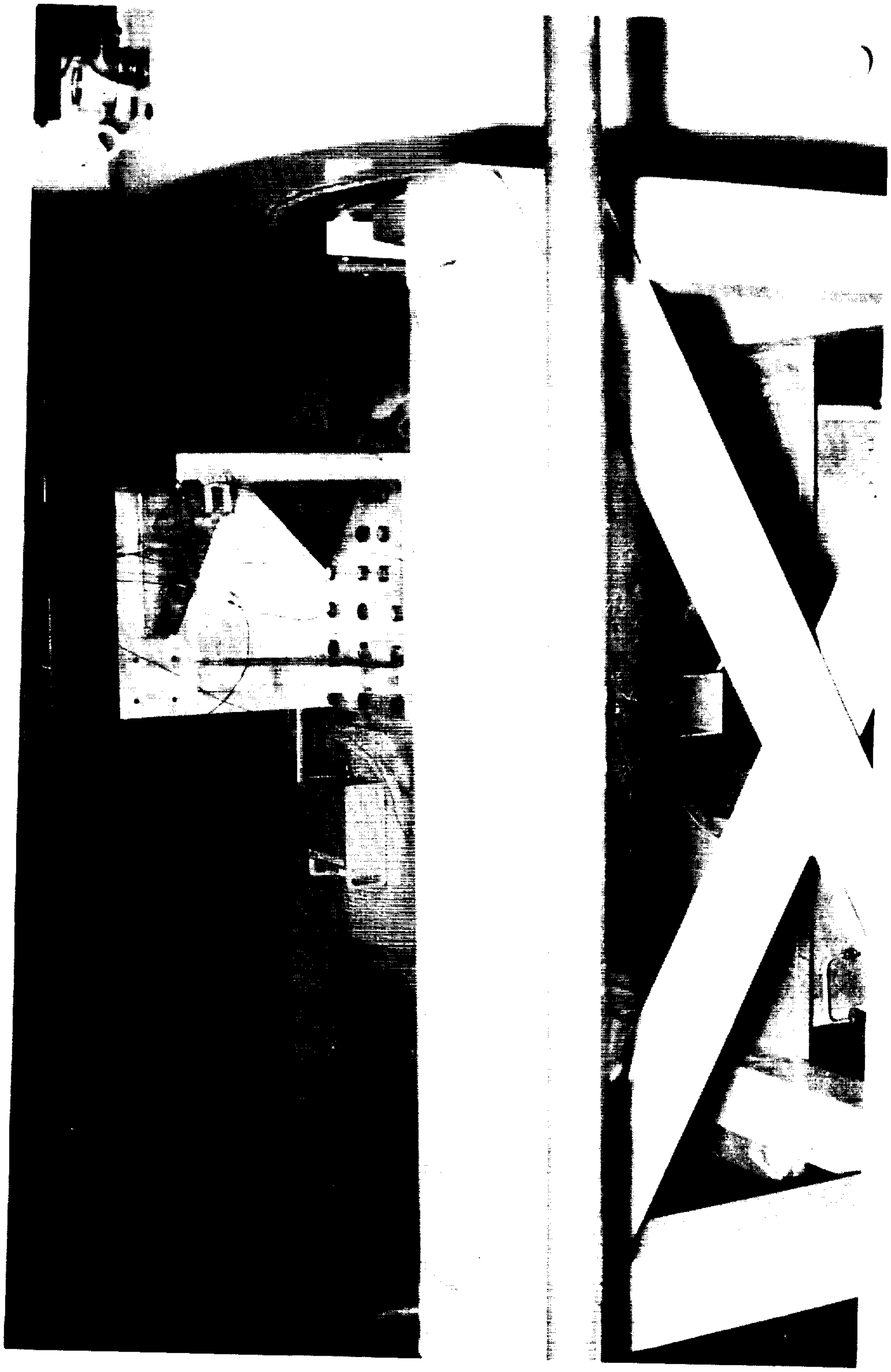

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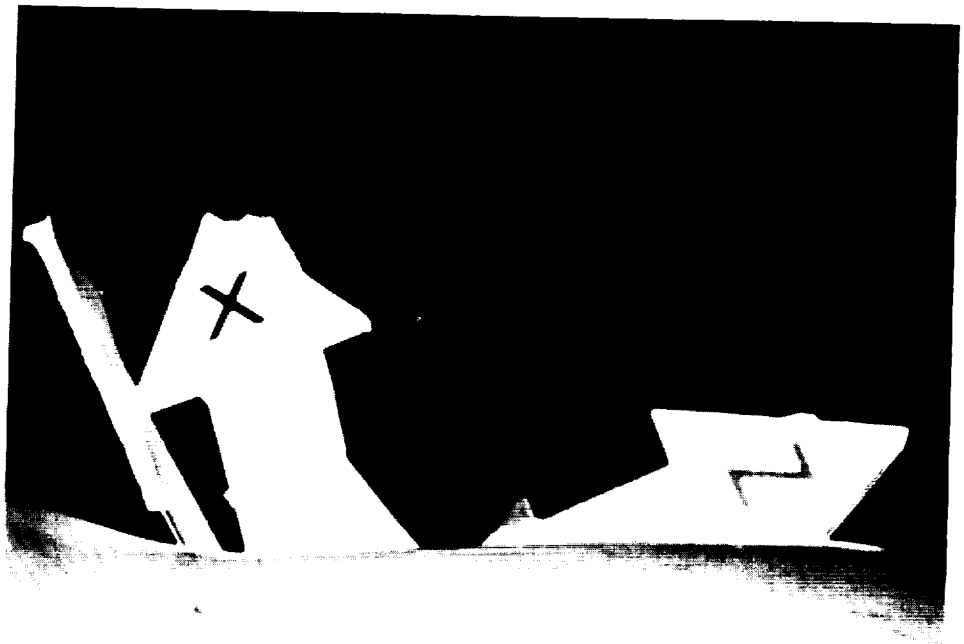

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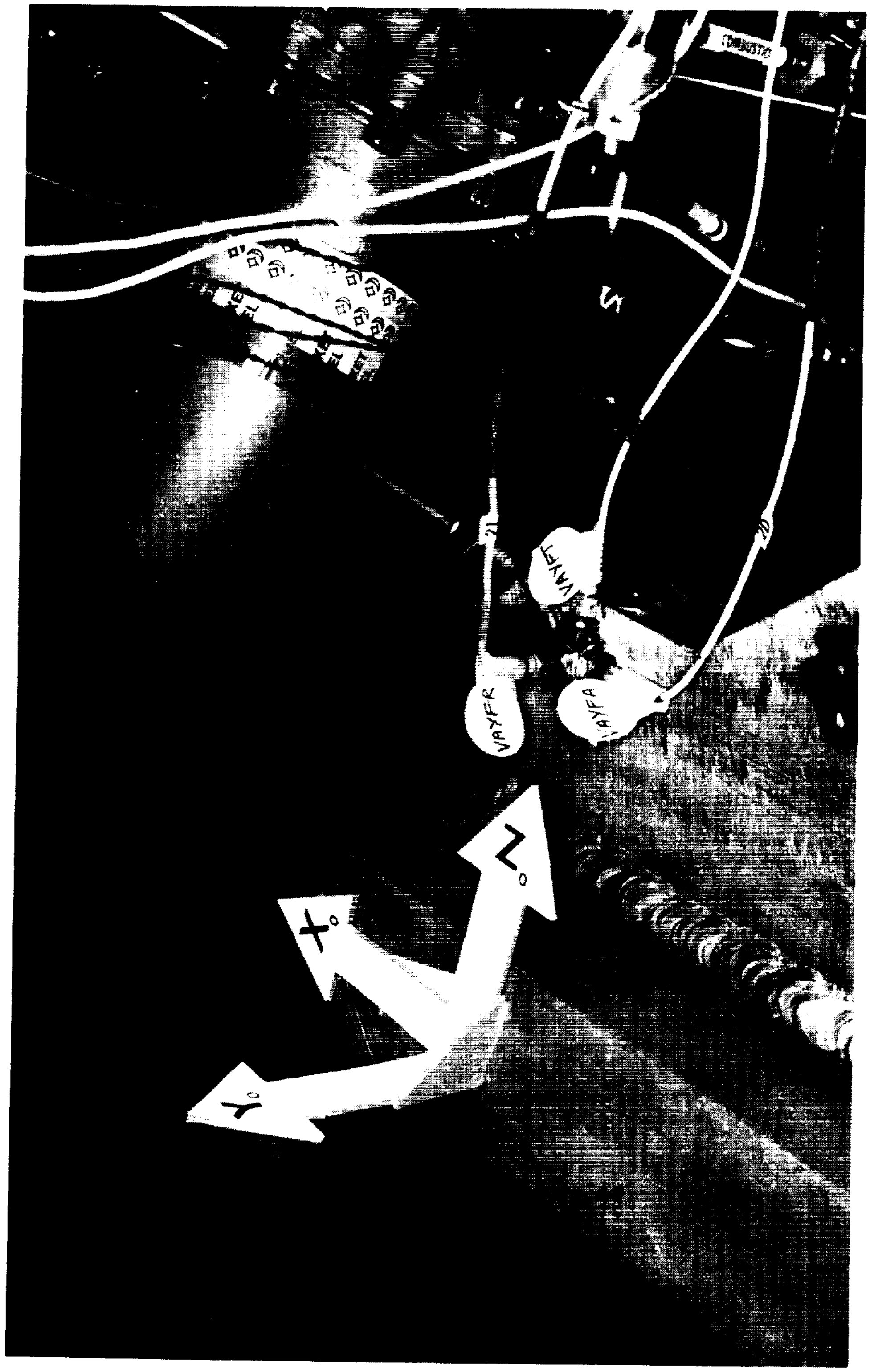

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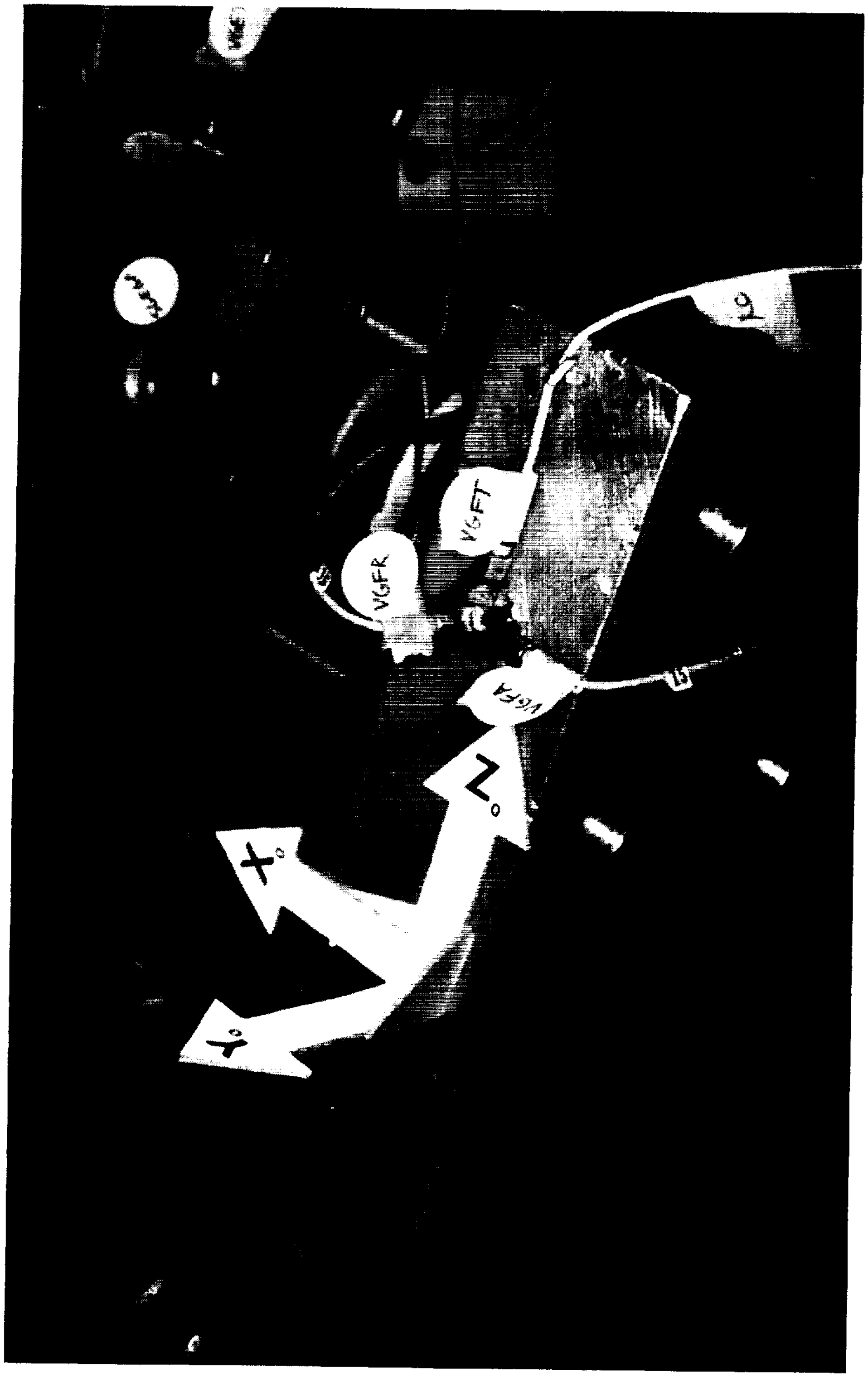

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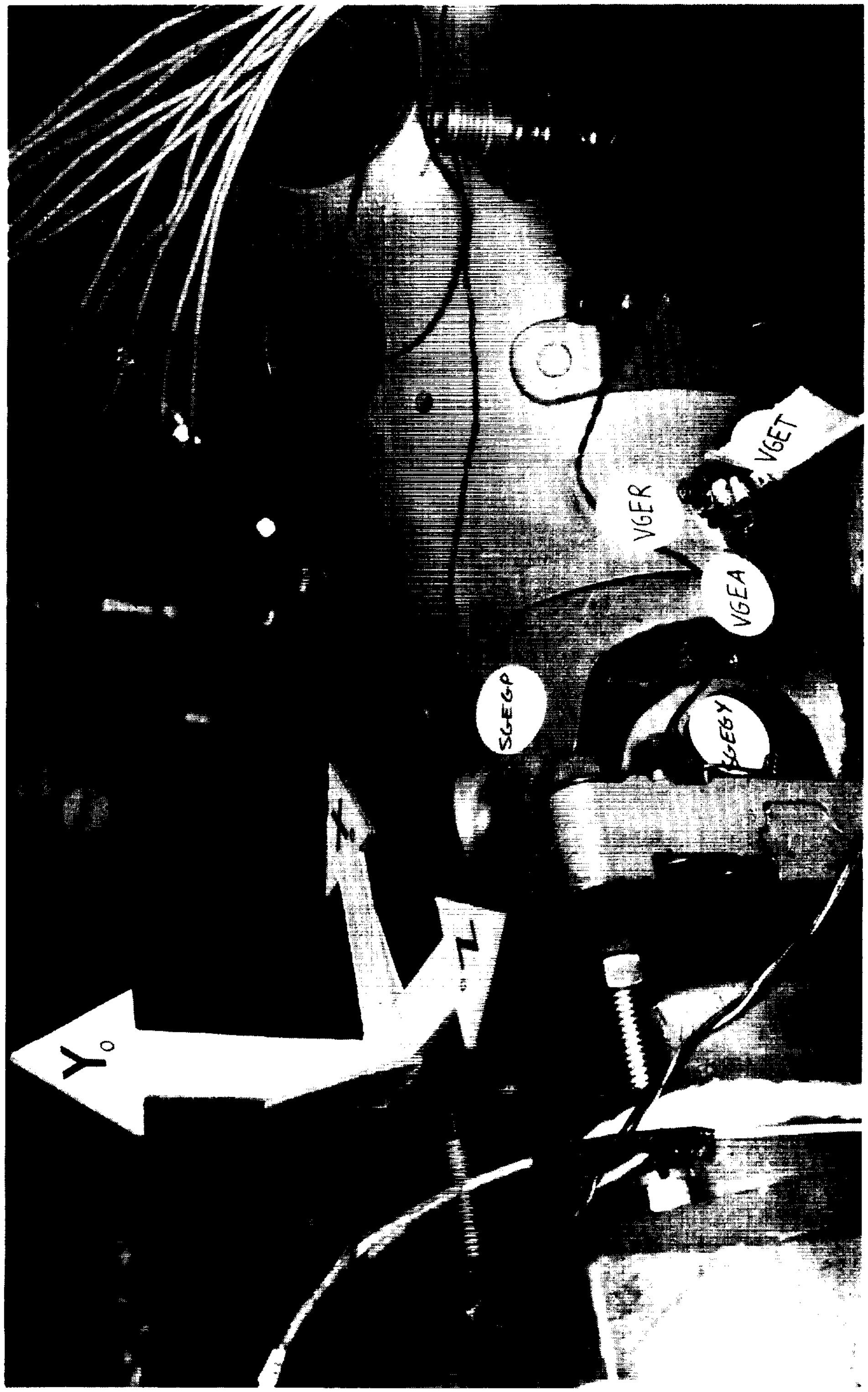
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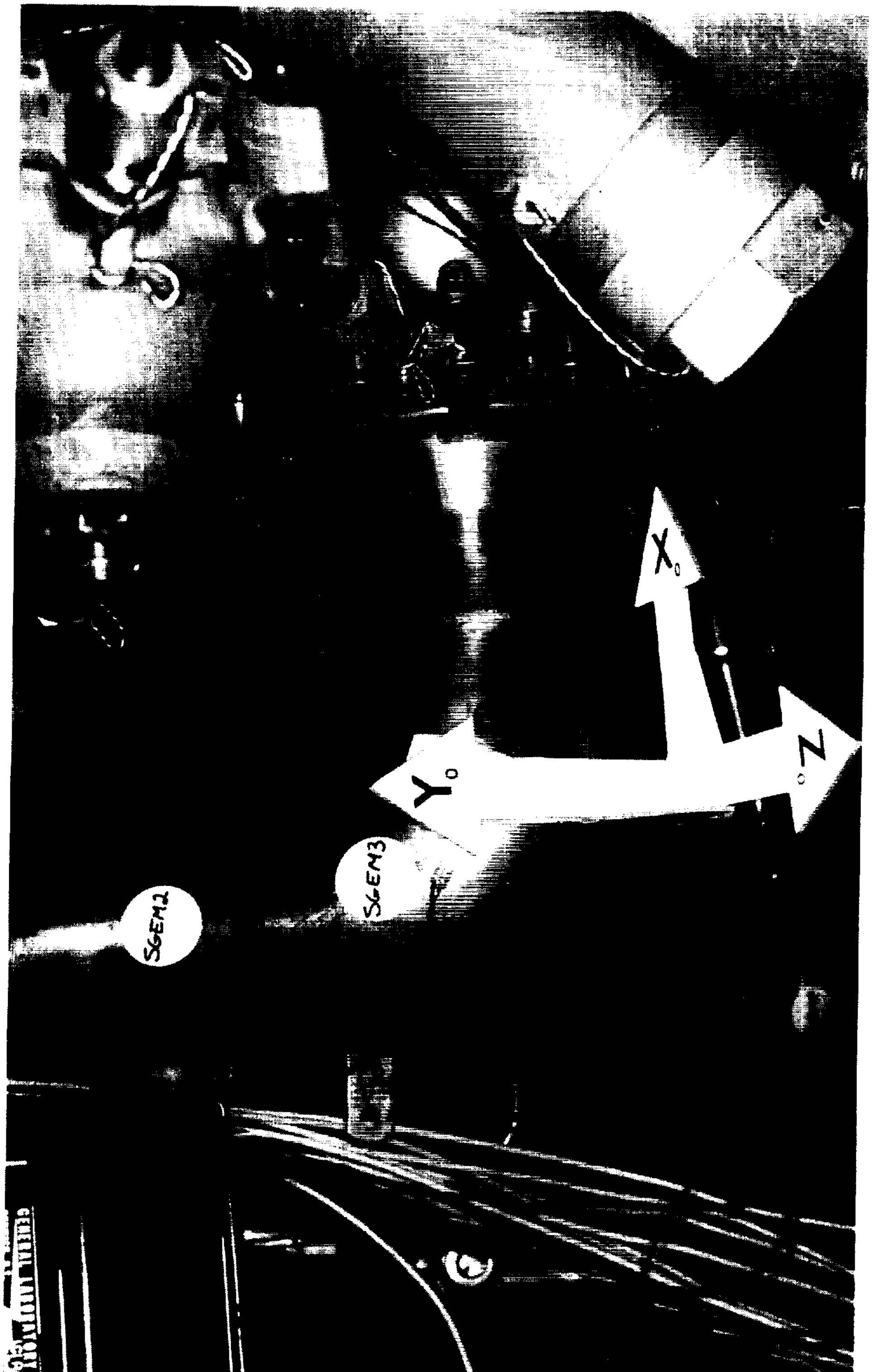

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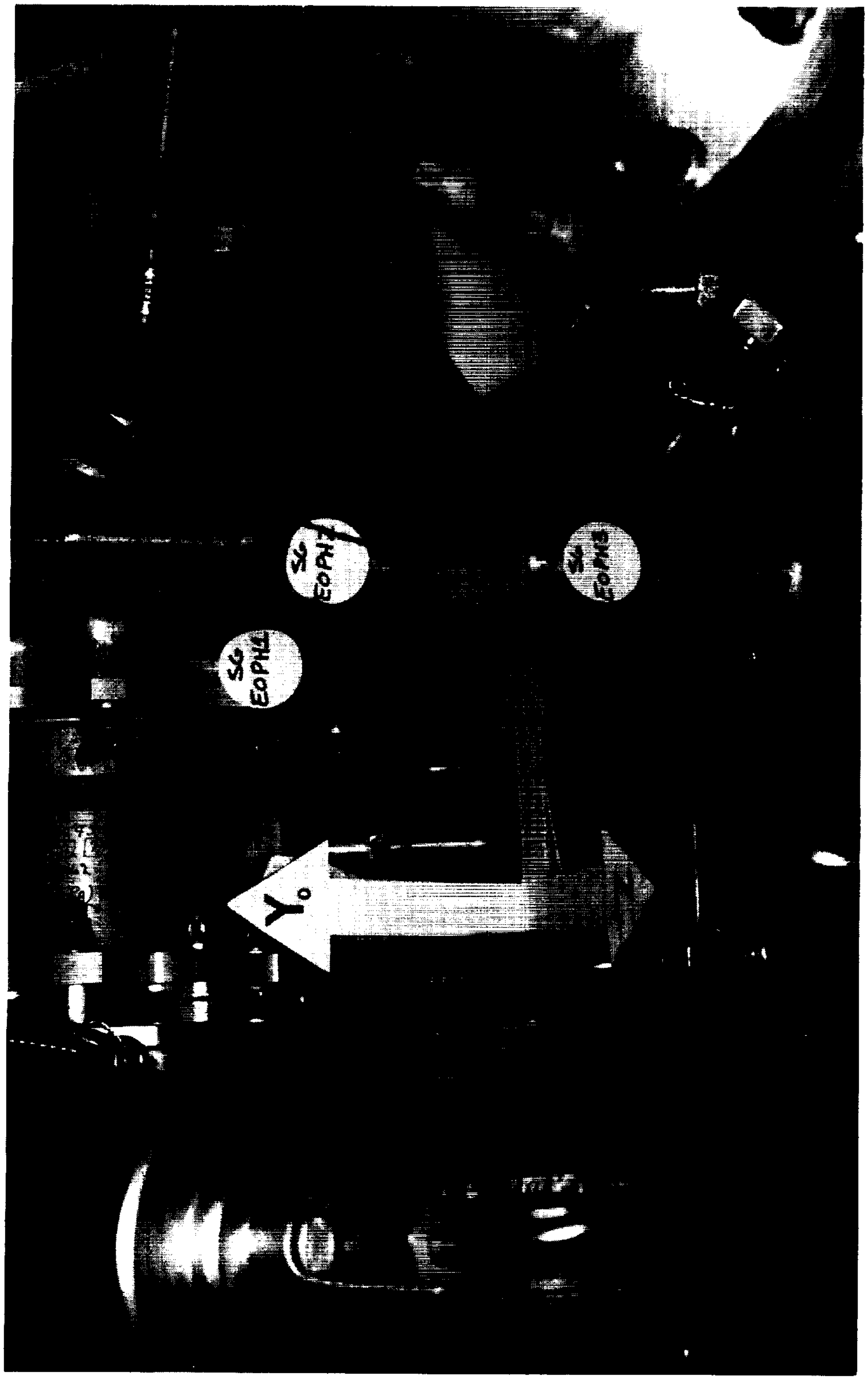

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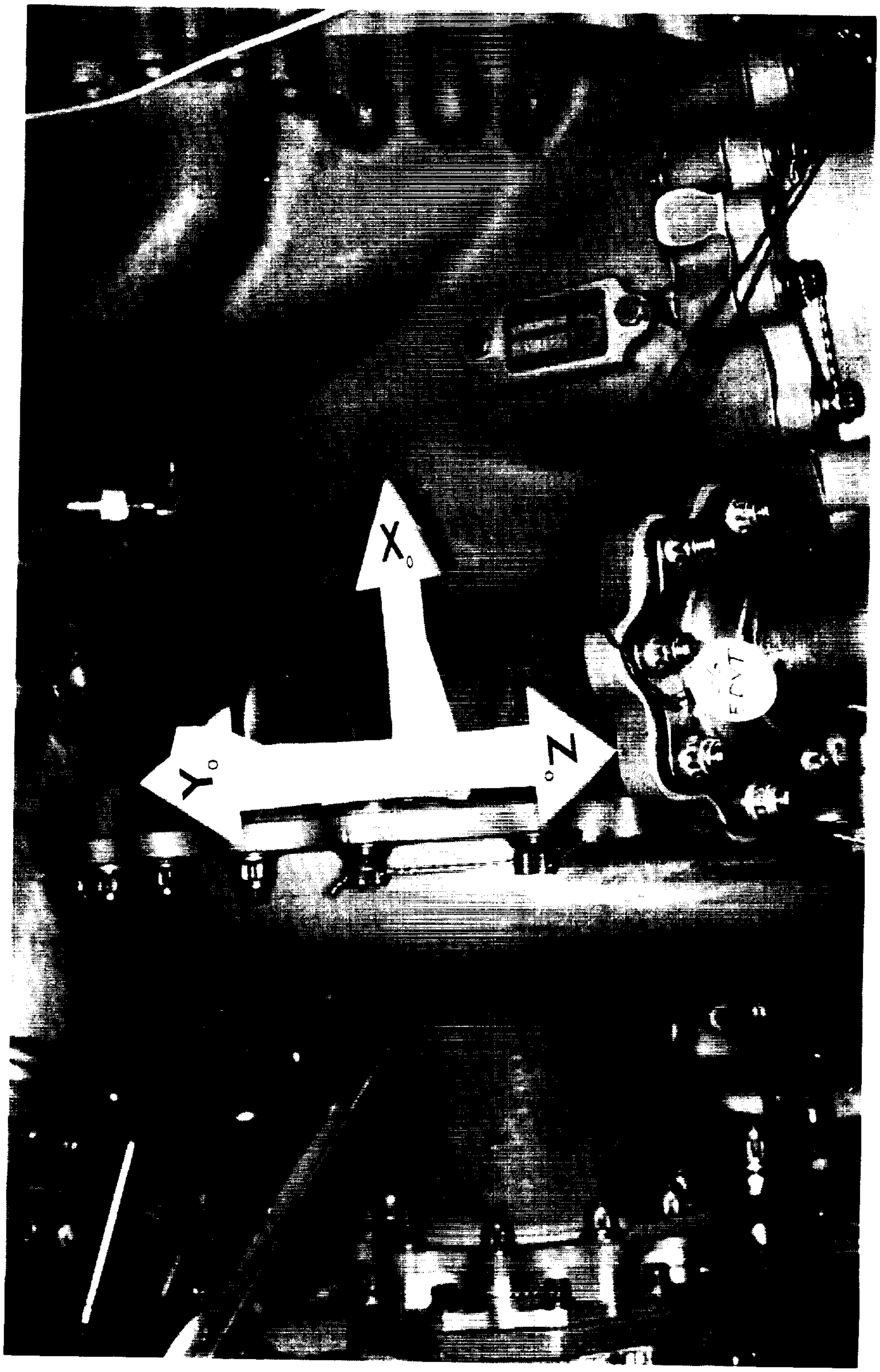

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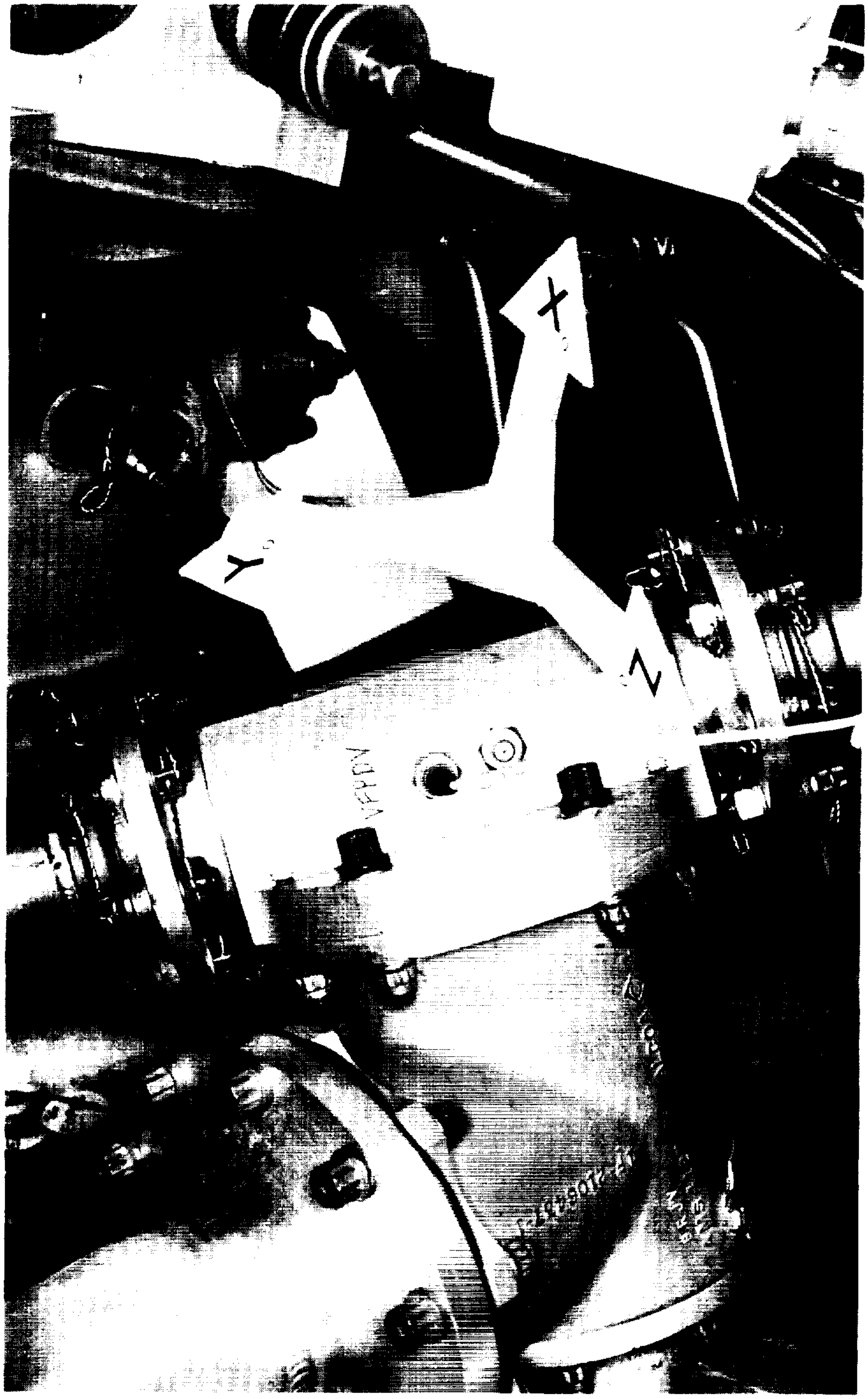

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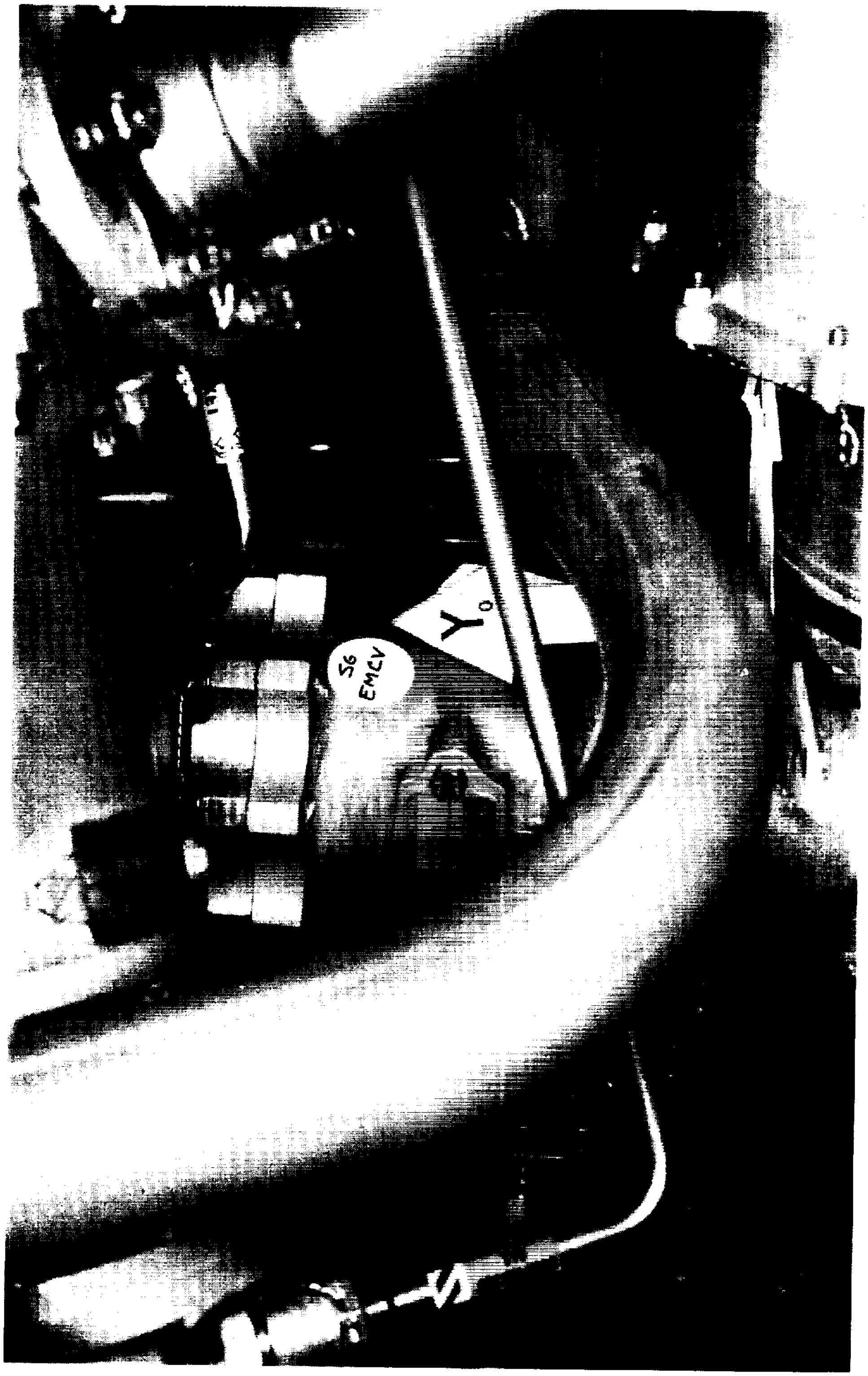

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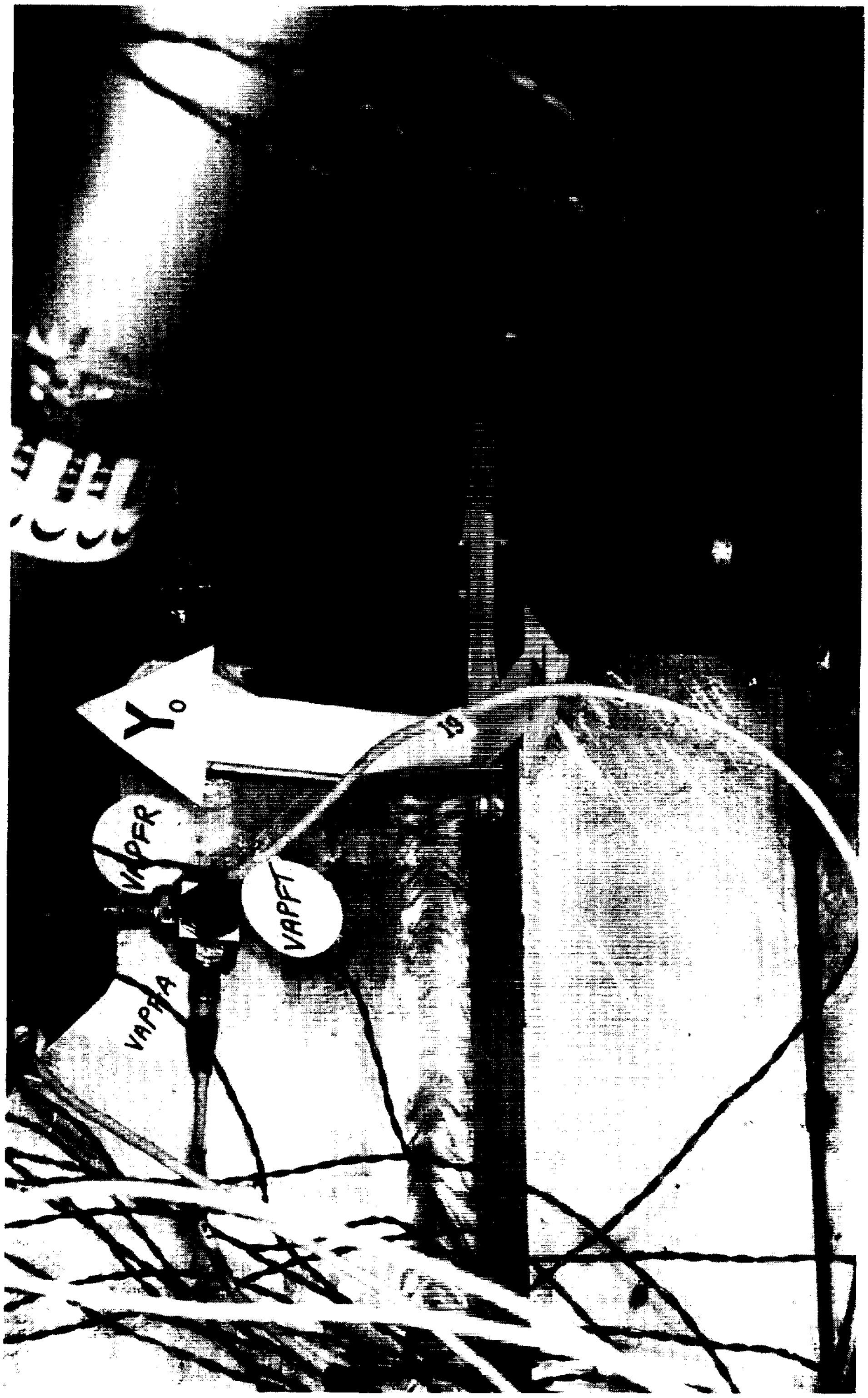

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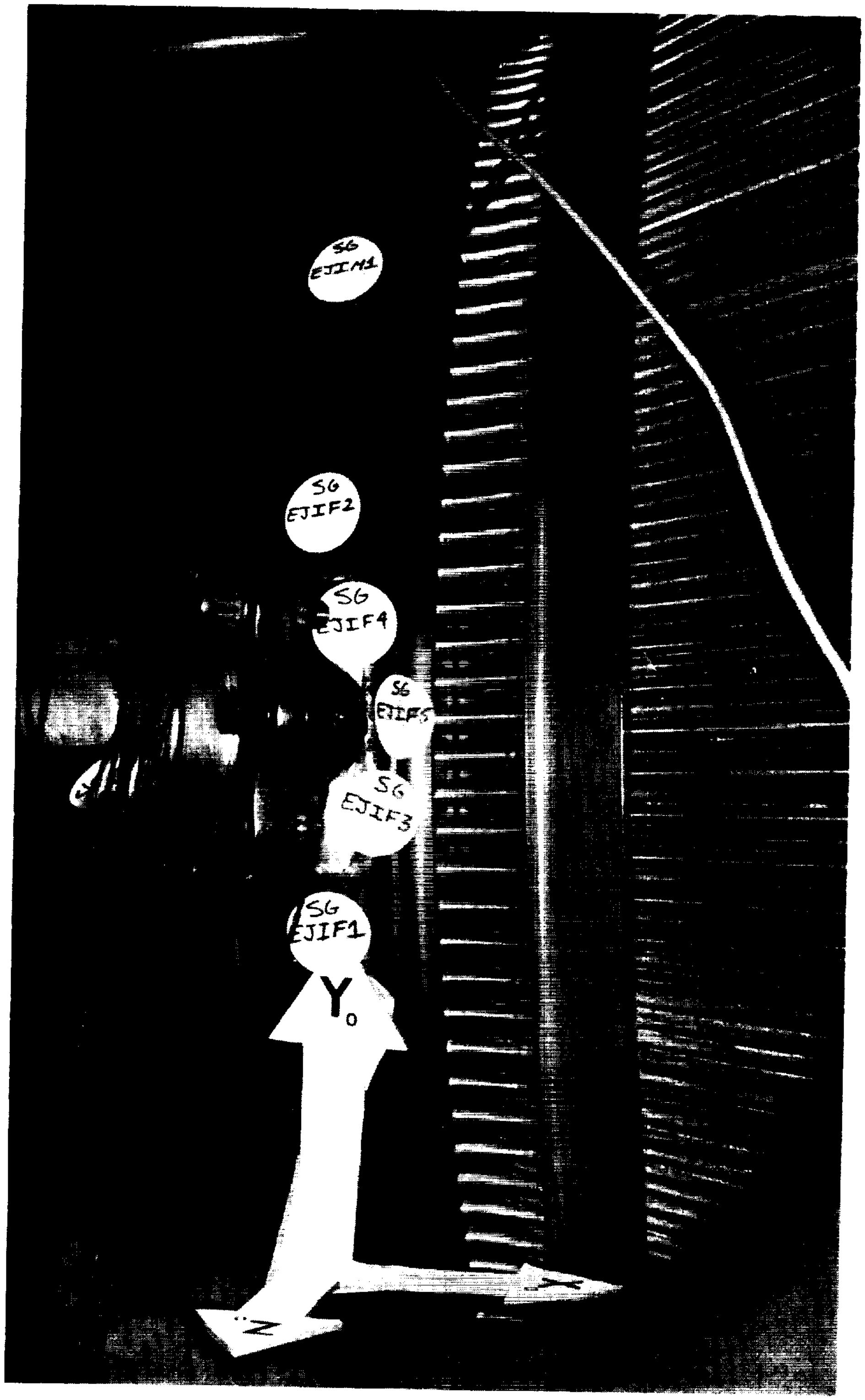

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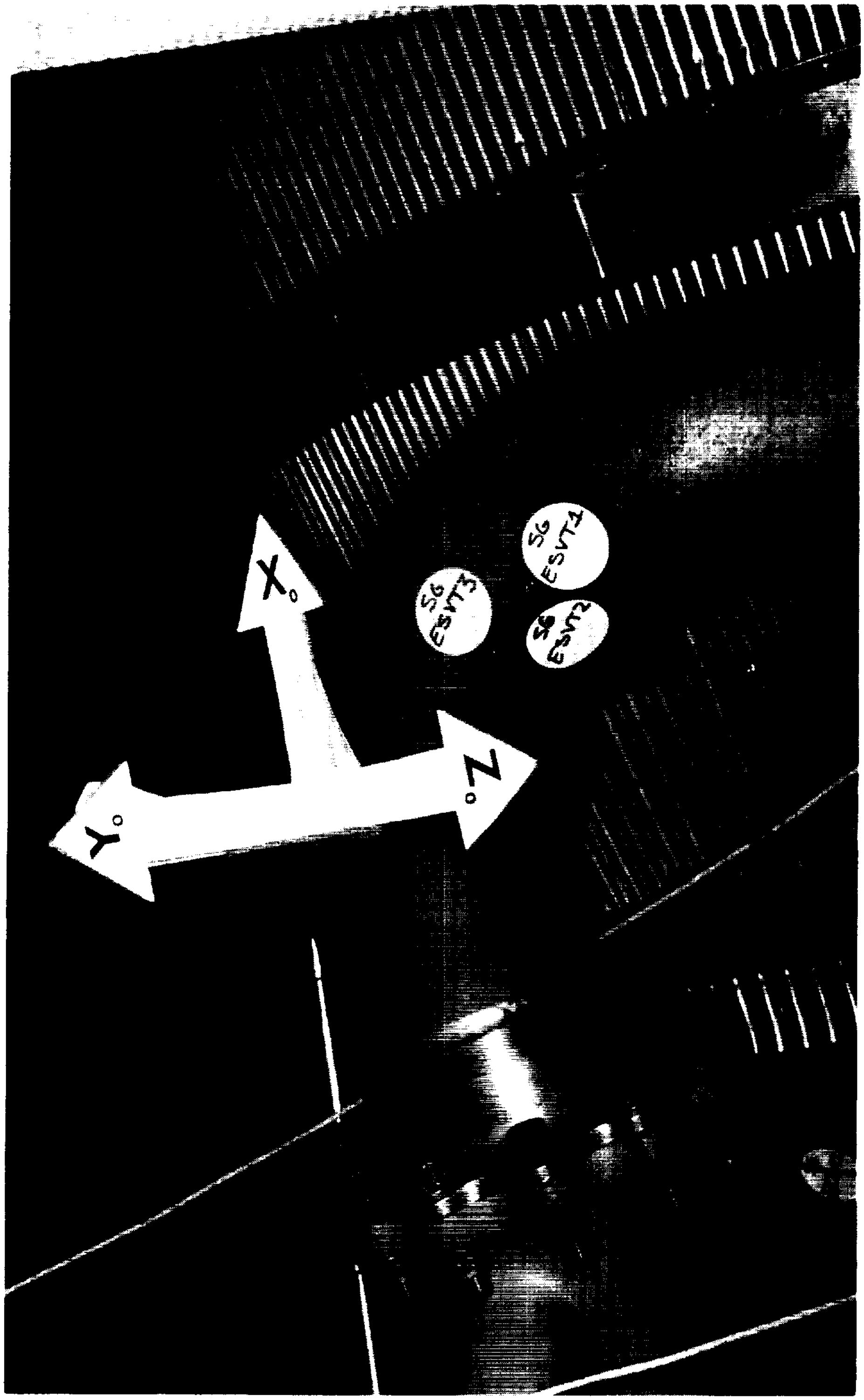

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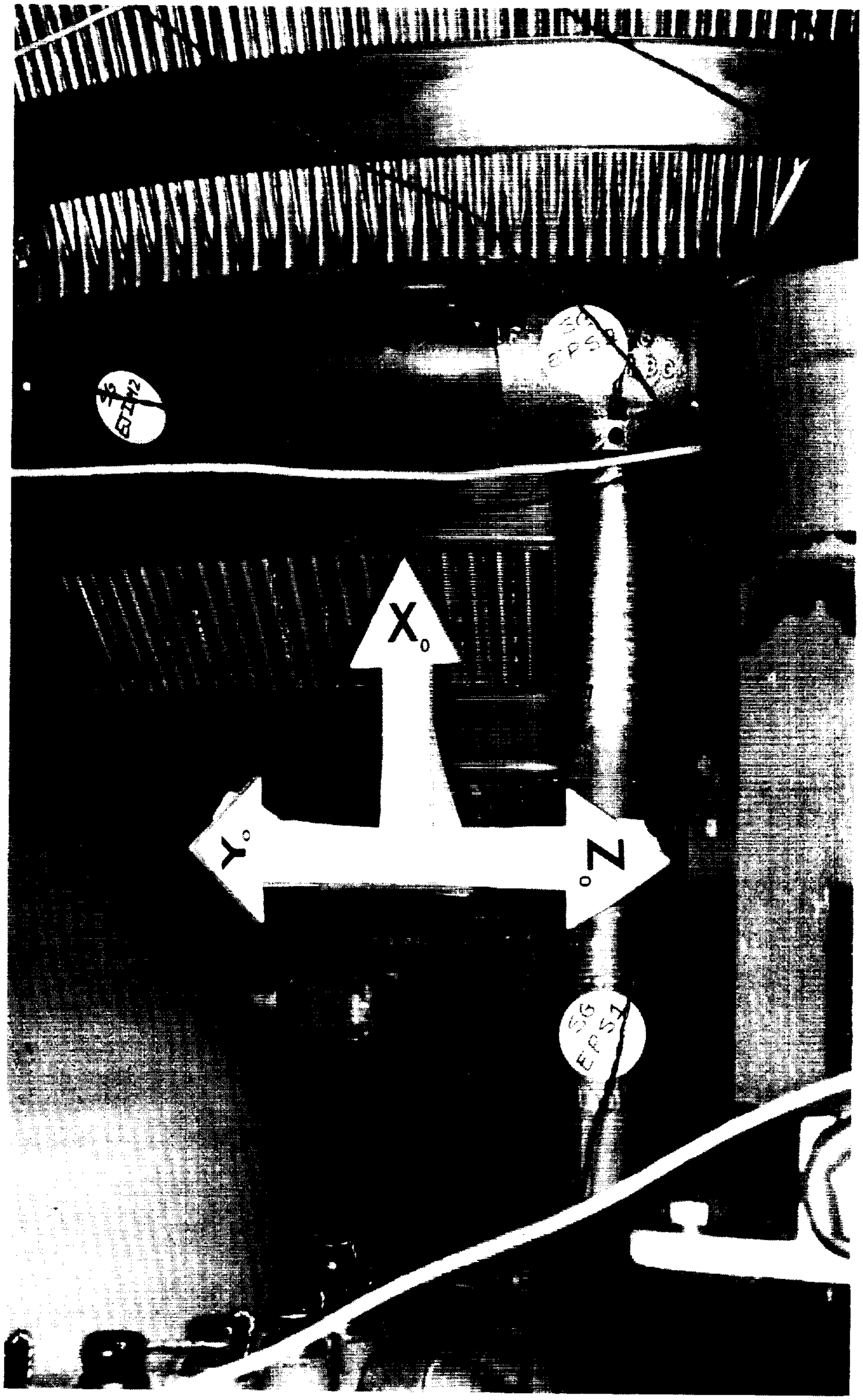

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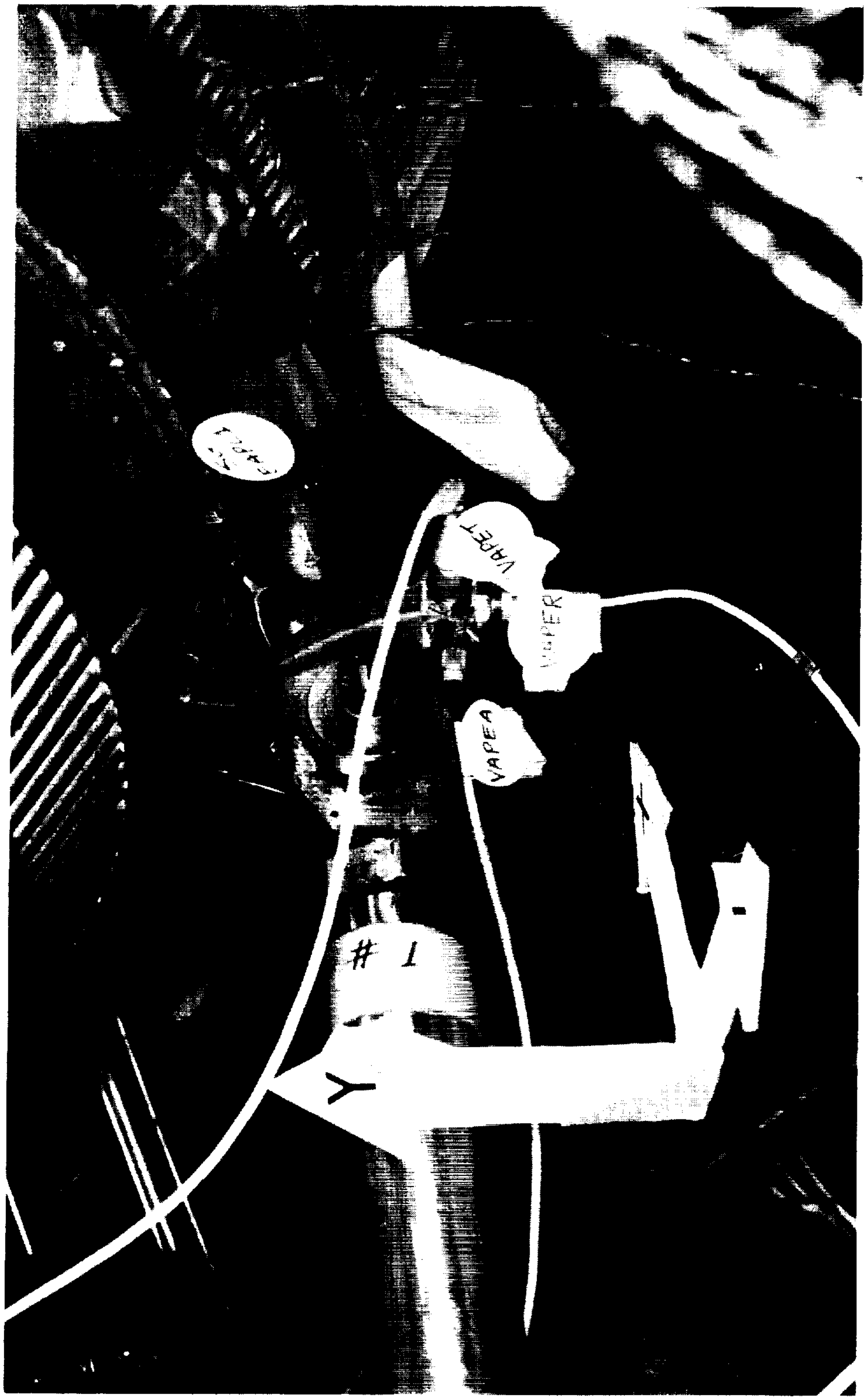
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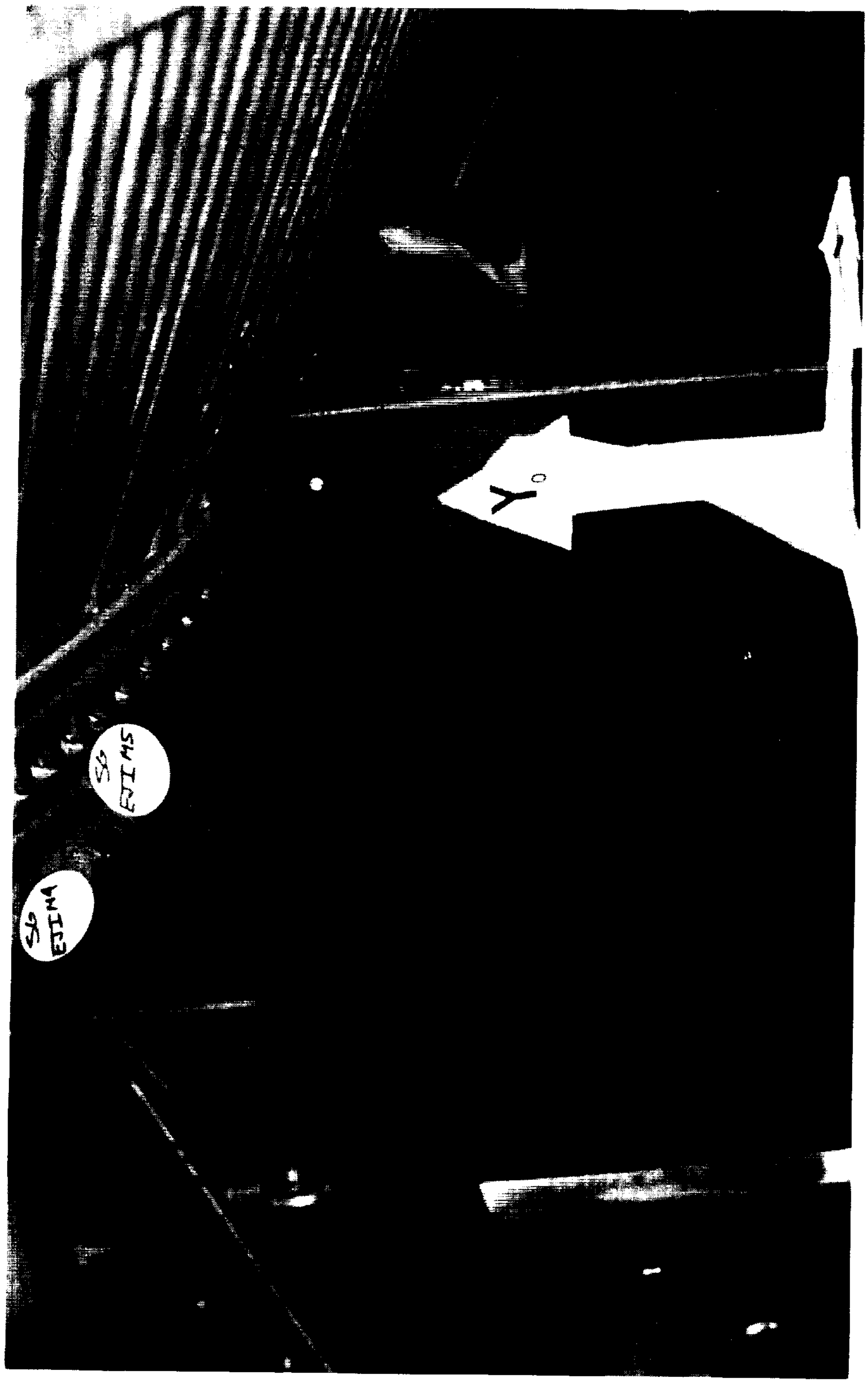

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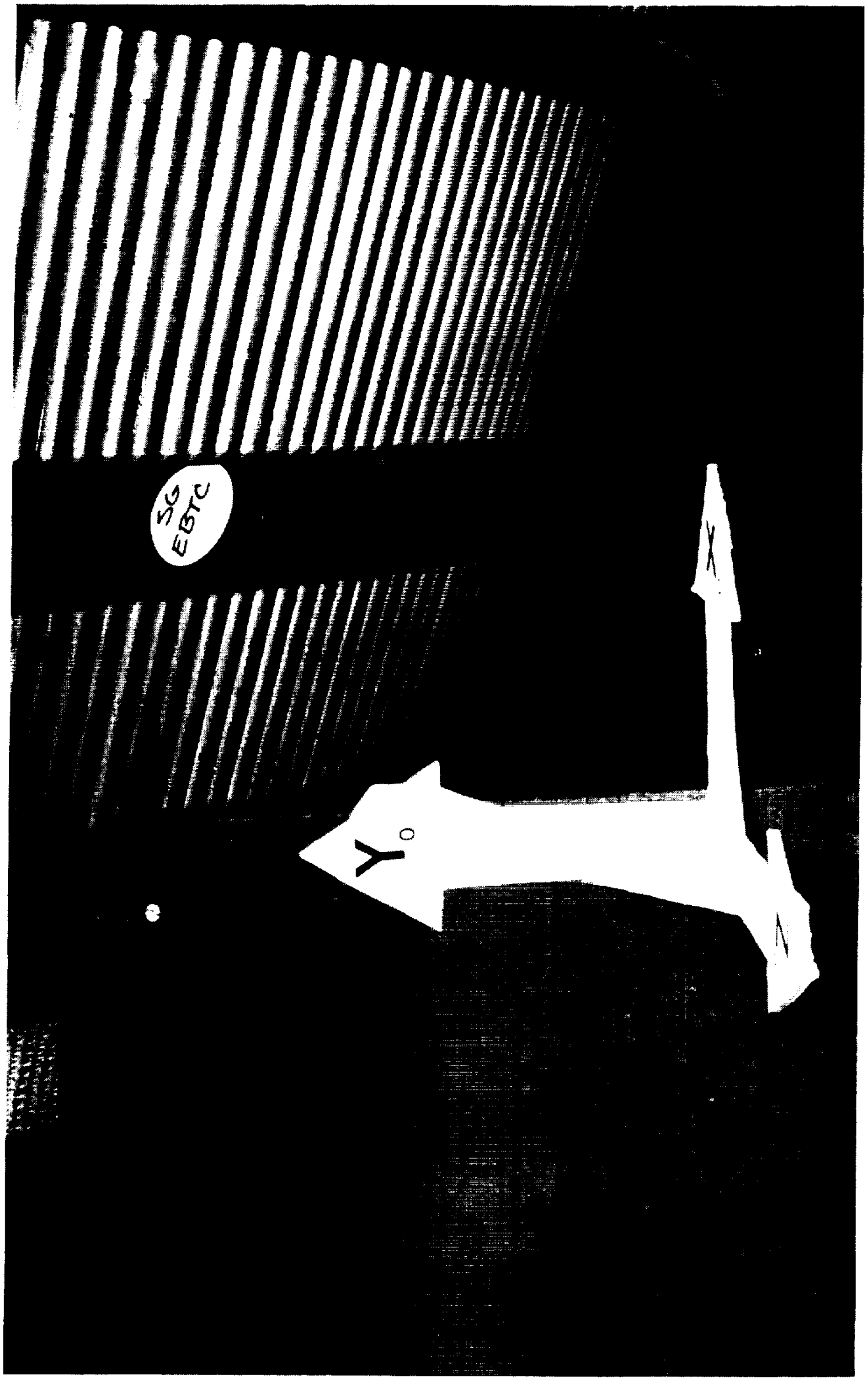

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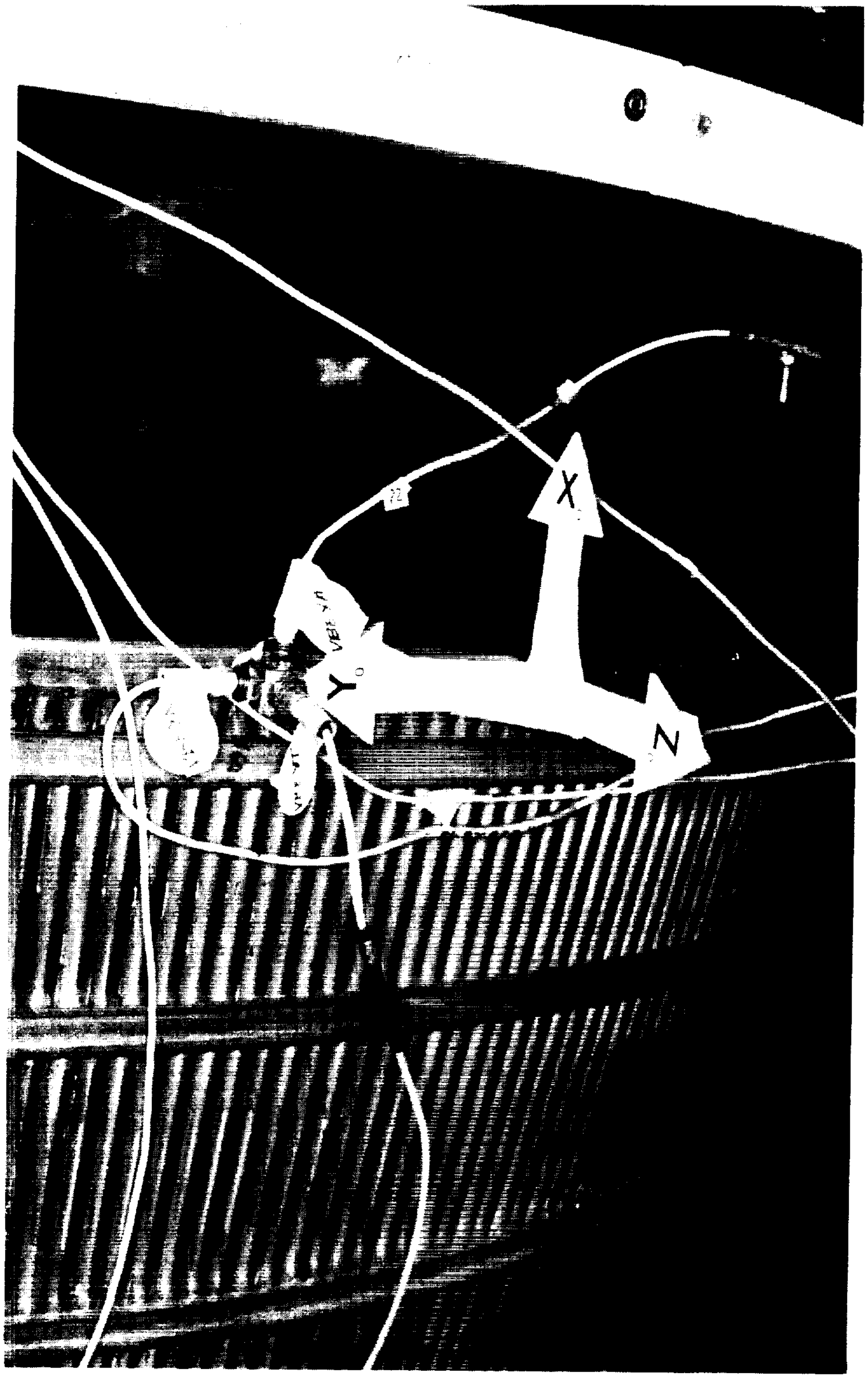

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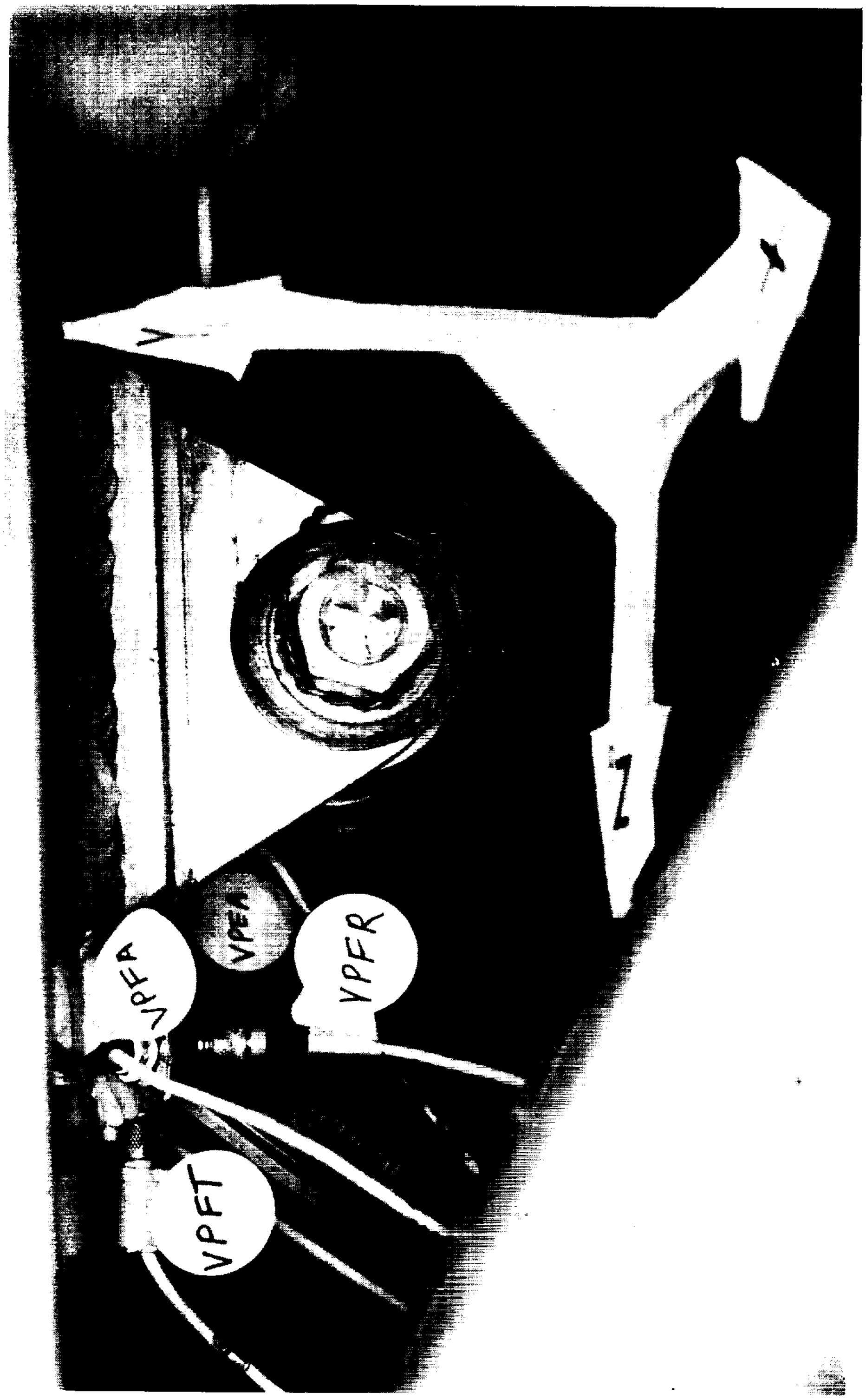

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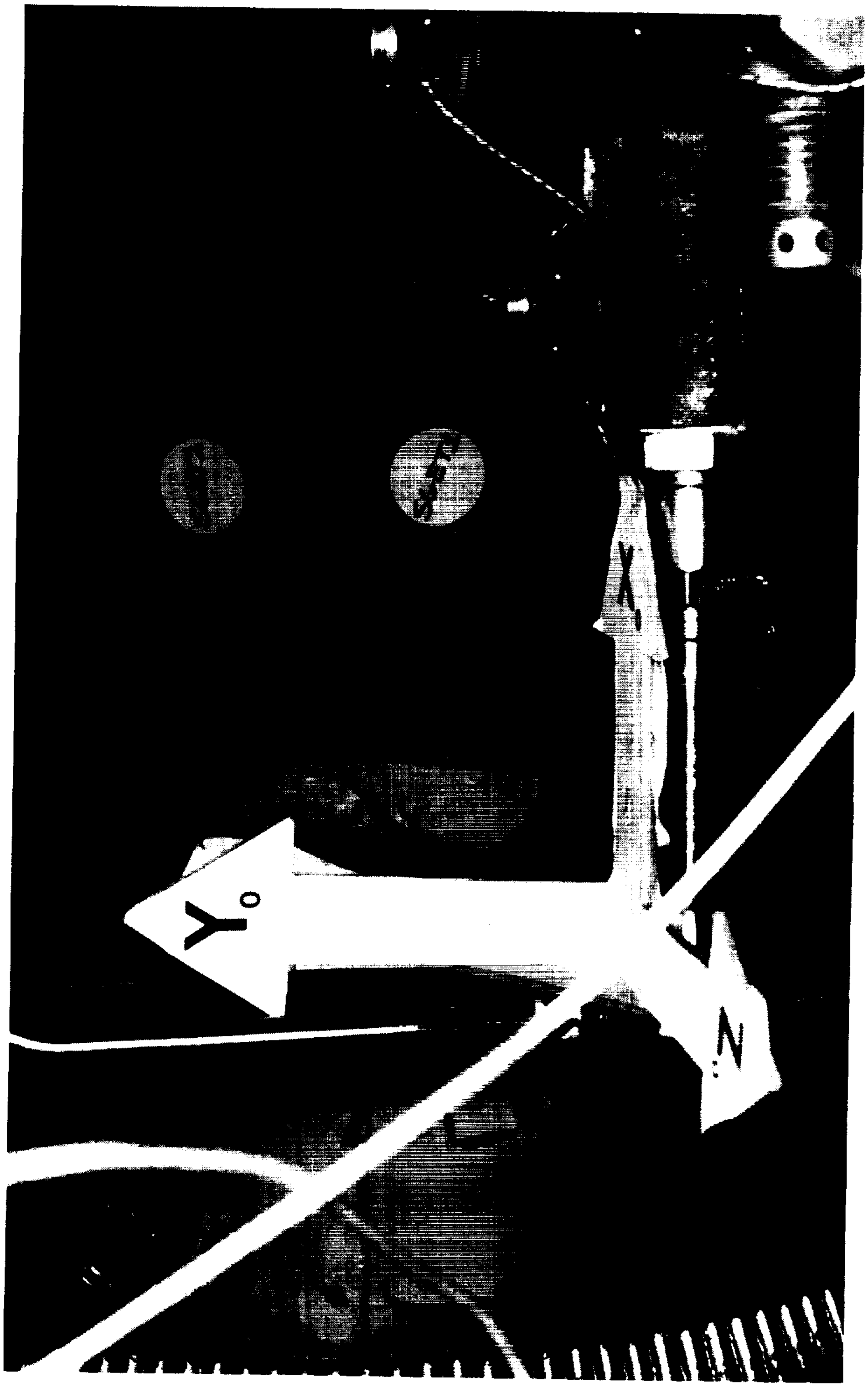

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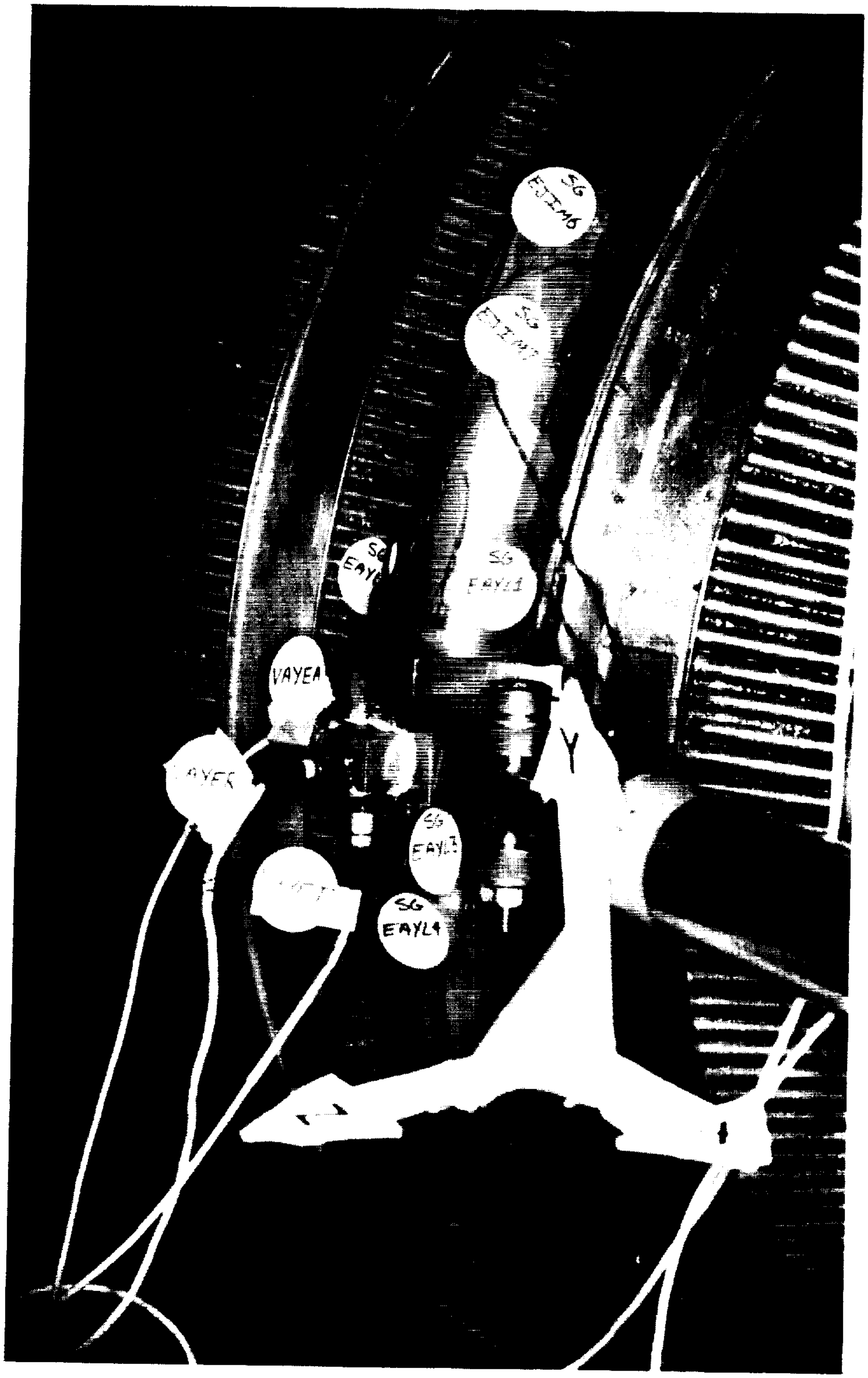

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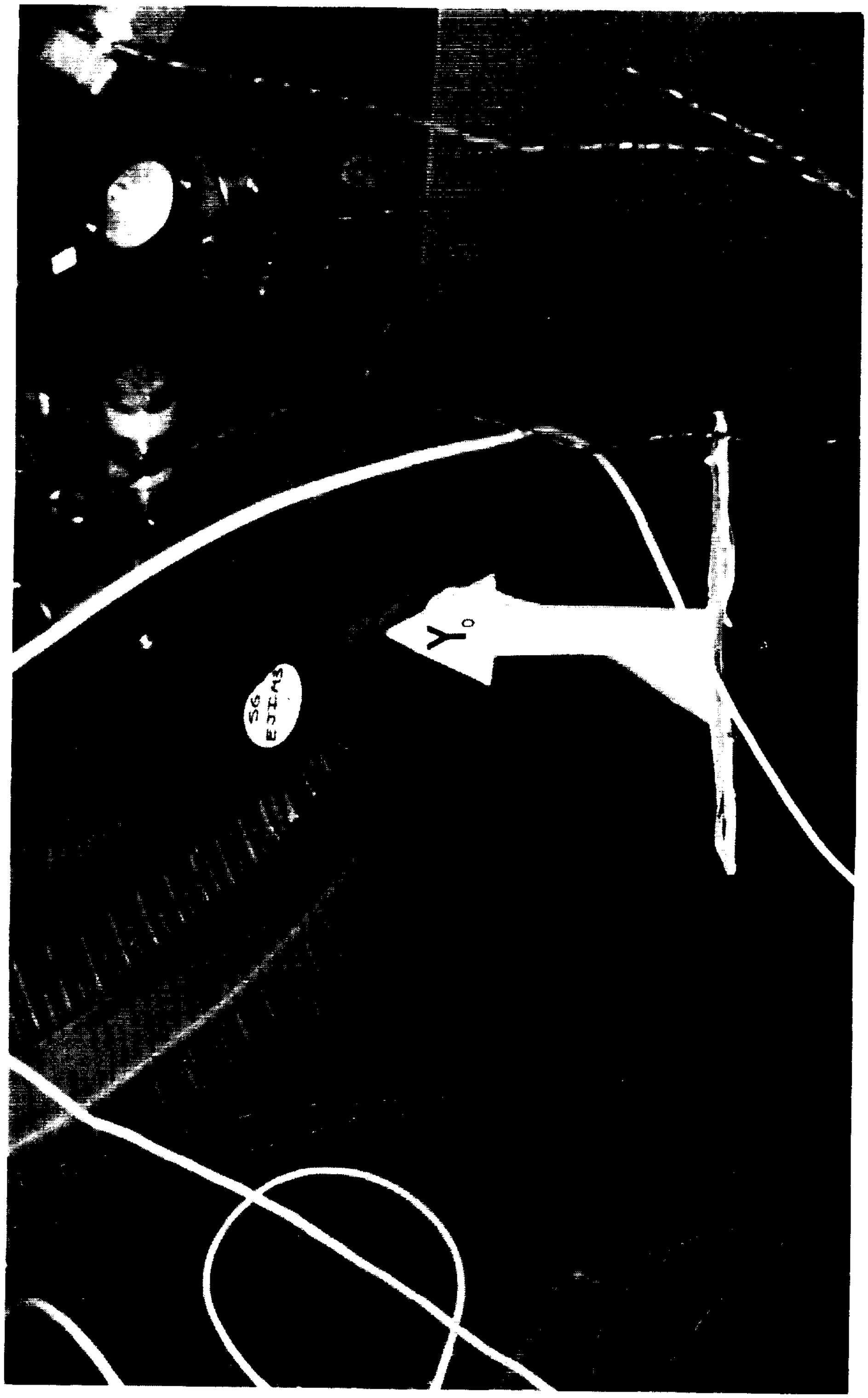

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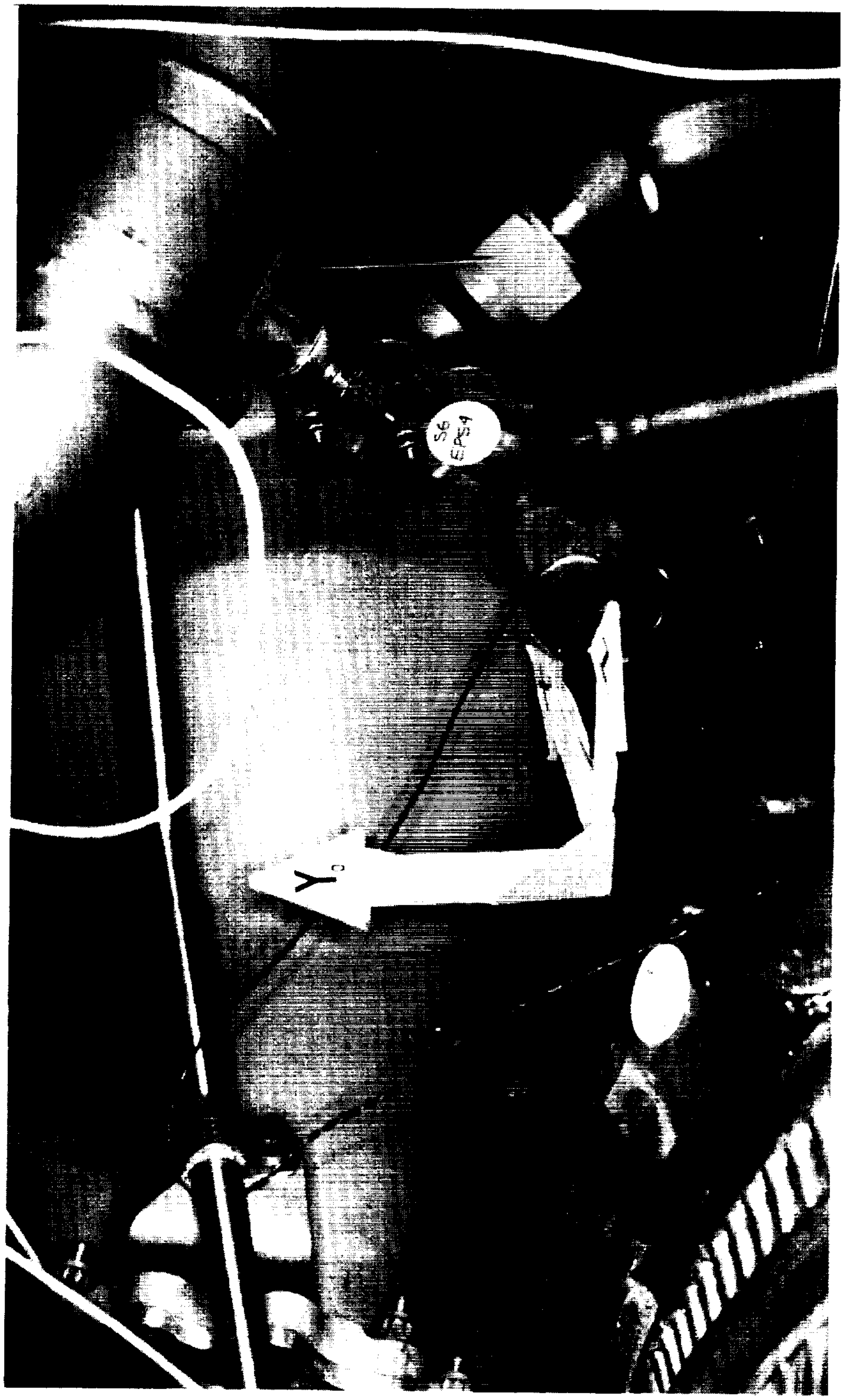
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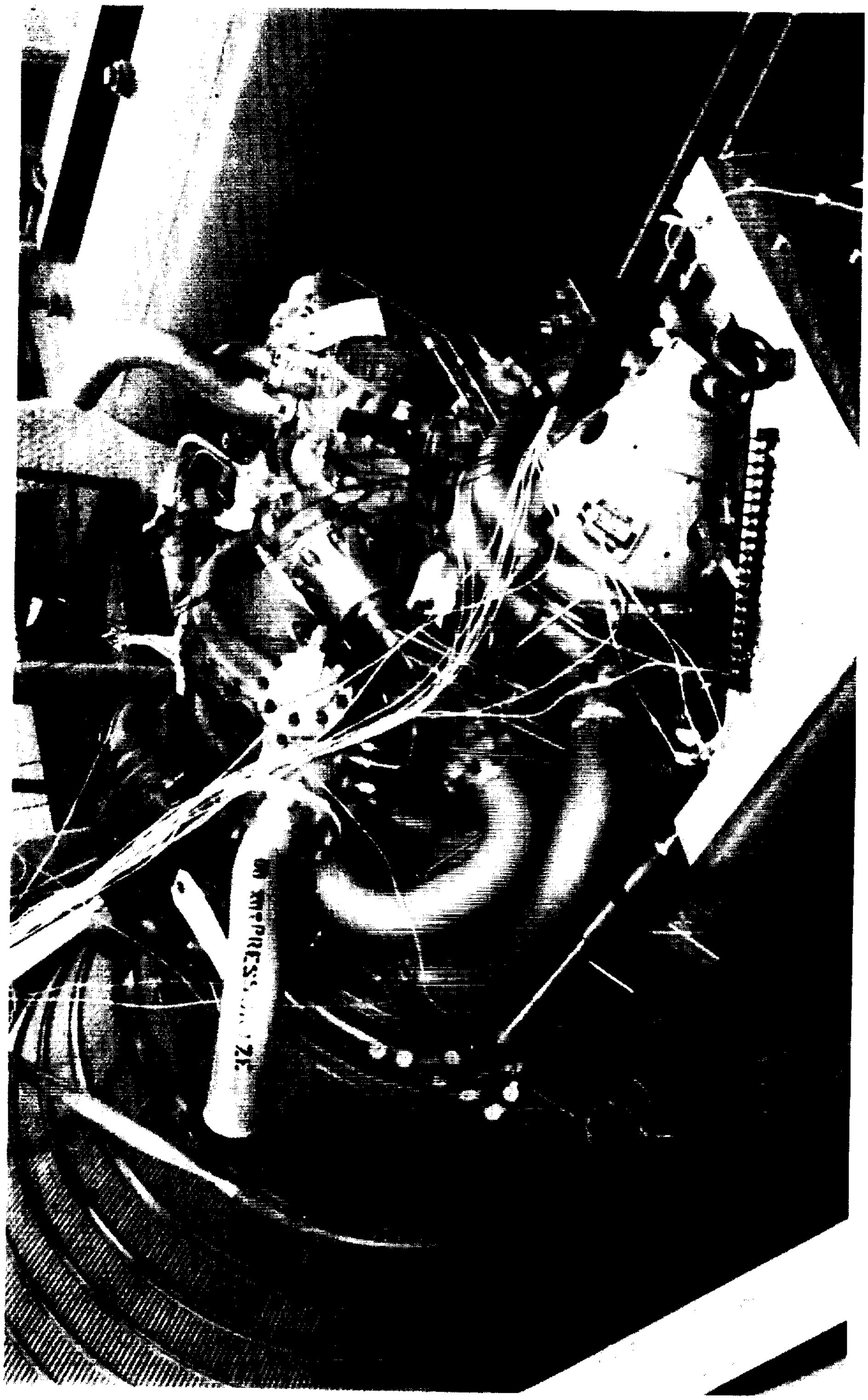

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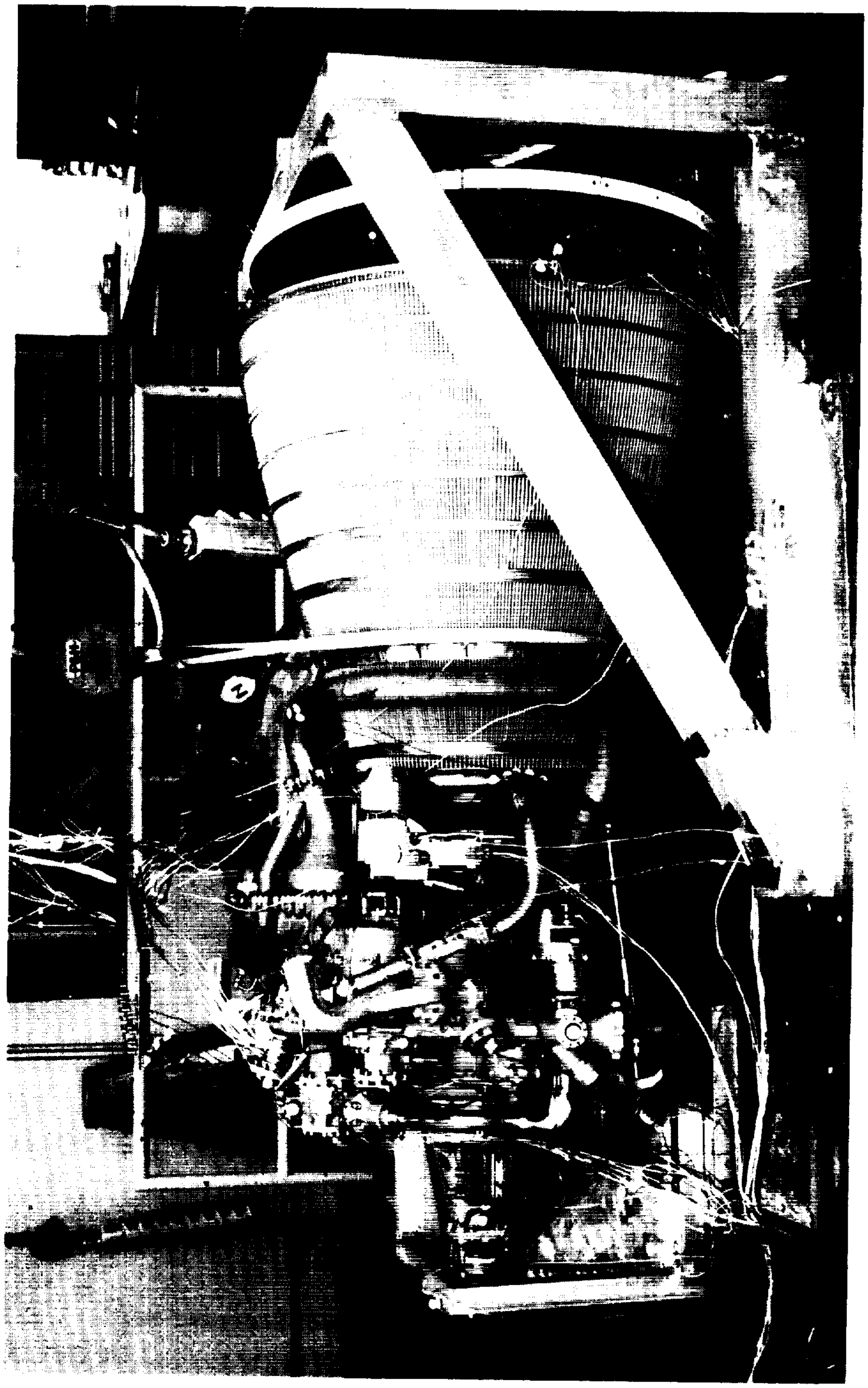

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APPENDIX B
RL10A-3-3A ENGINE XR105 RANDOM VIBRATORY QUALIFICATION INSTRUMENTATION

RL10A-3-3A ENGINE XR105 RANDOM VIBRATORY QUALIFICATION INSTRUMENTATION

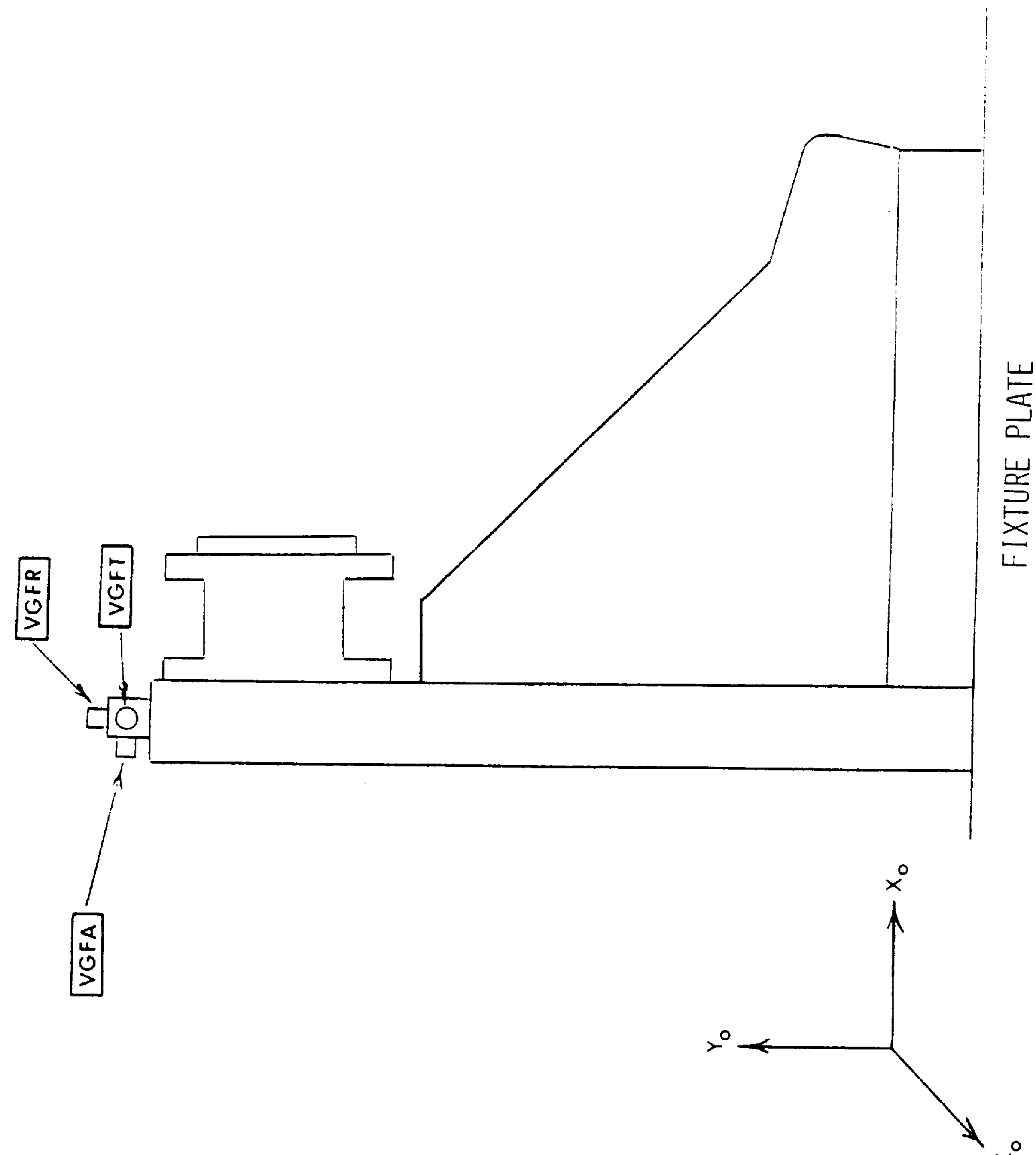

FIGURE 1

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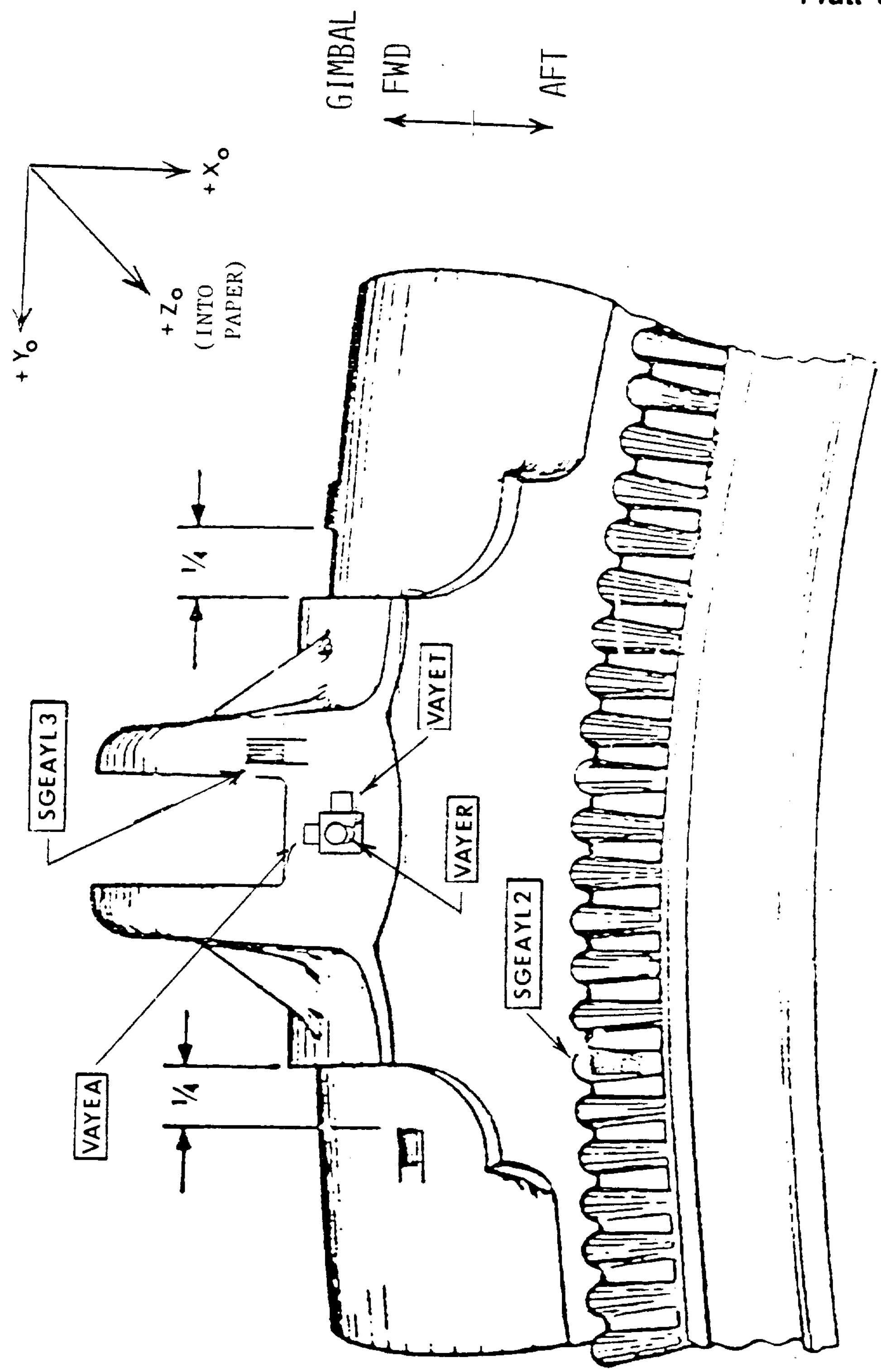

FIGURE 2

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RL10A-3-3A ENGINE XR105 RANDOM VIBRATORY QUALIFICATION INSTRUMENTATION

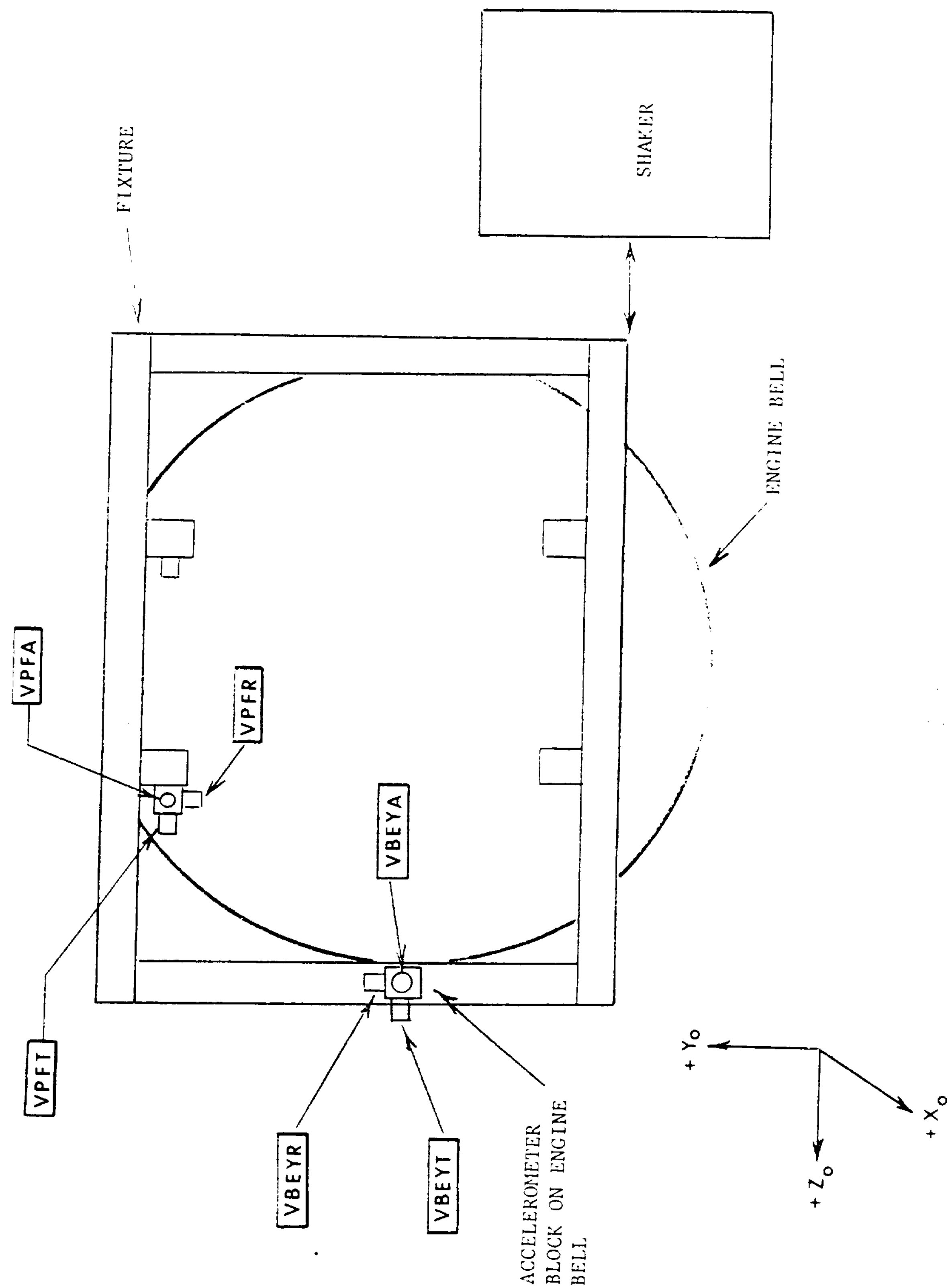

FIGURE 3

RL10A-3-3A ENGINE XR105 RANDOM VIBRATORY QUALIFICATION INSTRUMENTATION

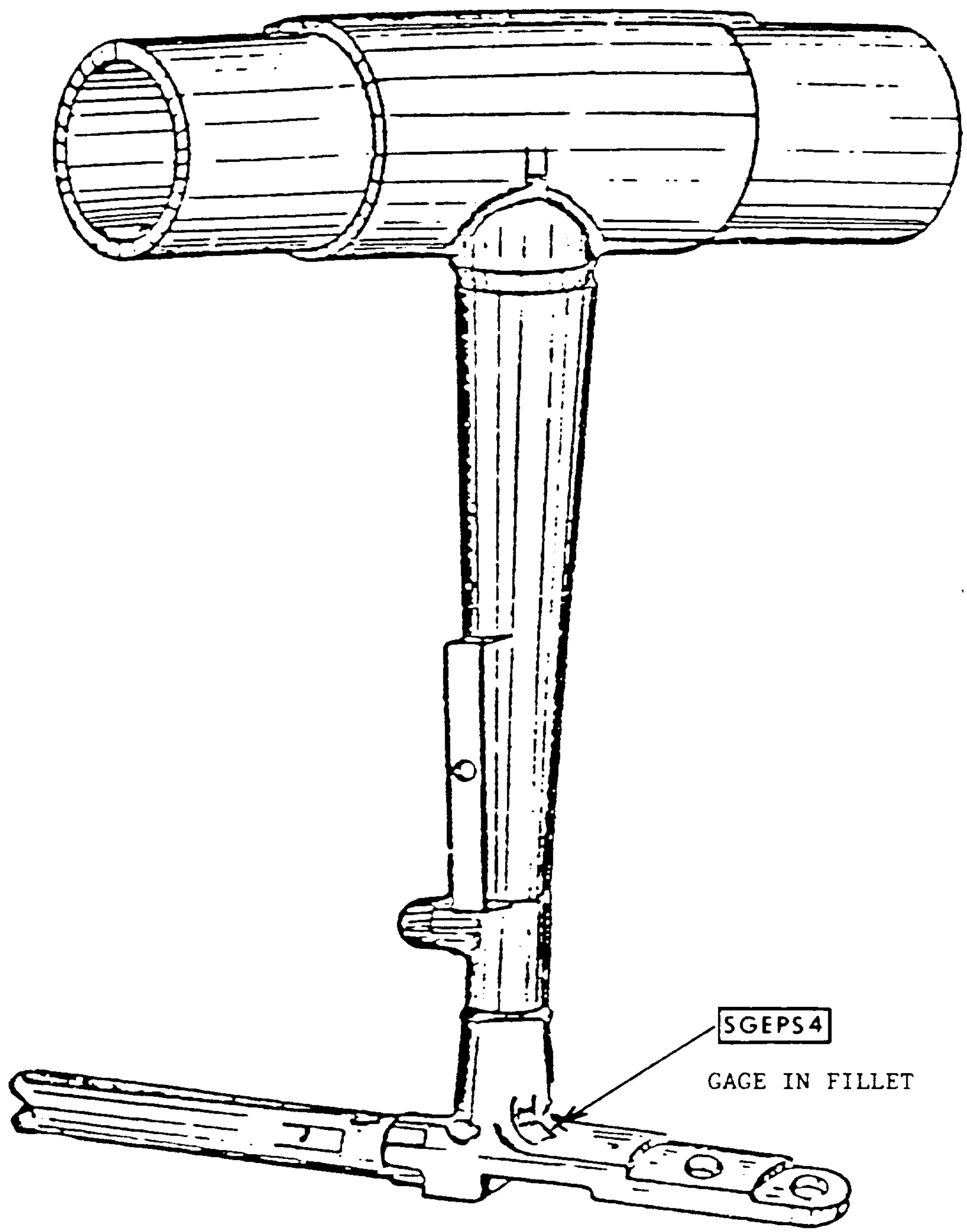

FIGURE 4

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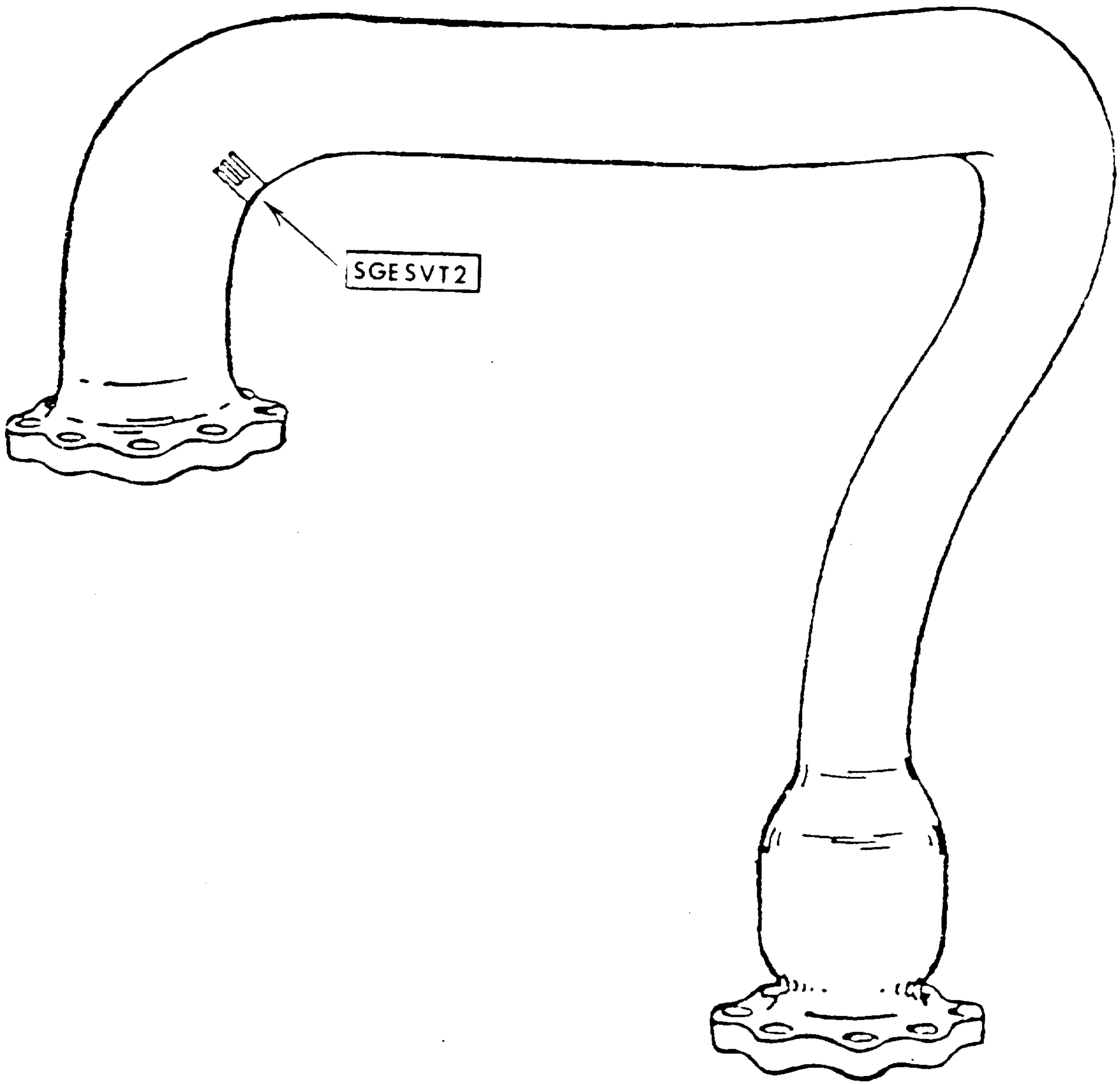

FIGURE 5

RL10A-3-3A ENGINE XR105 RANDOM VIBRATORY QUALIFICATION INSTRUMENTATION

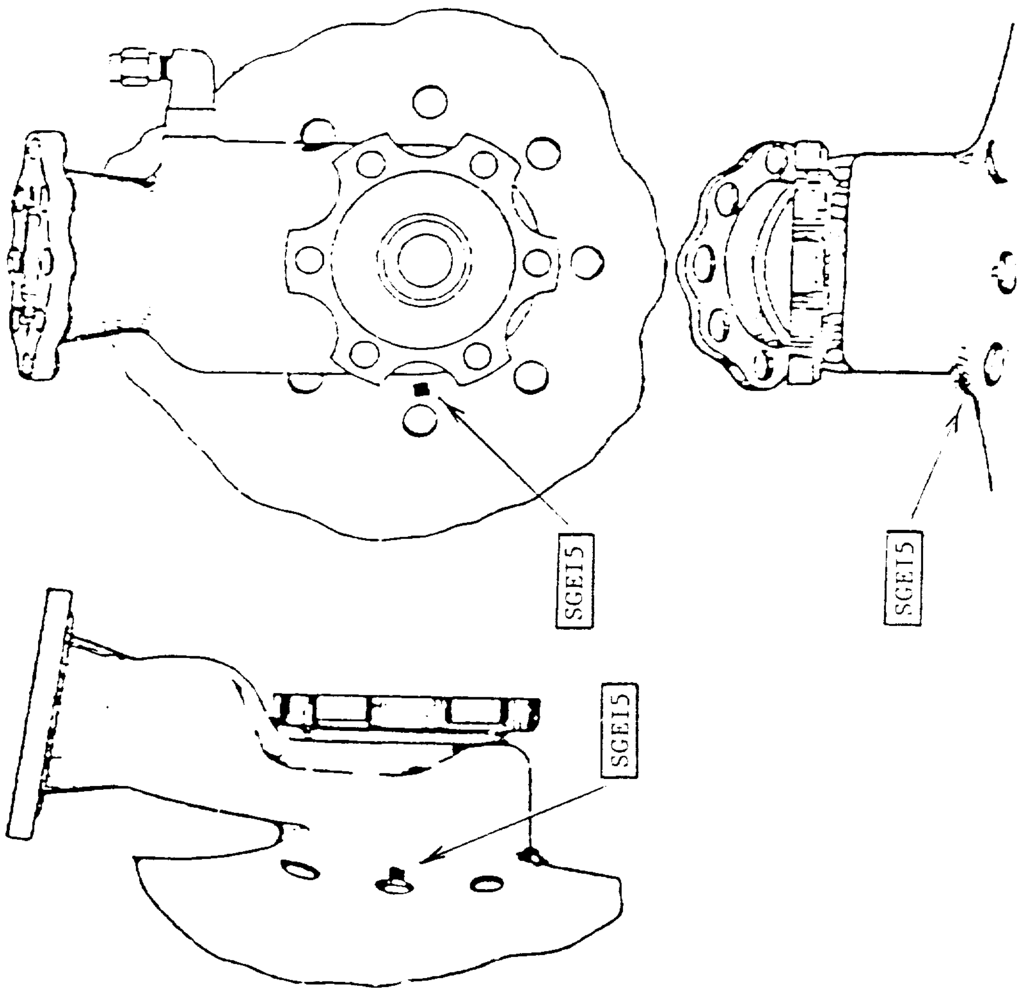

FIGURE 6

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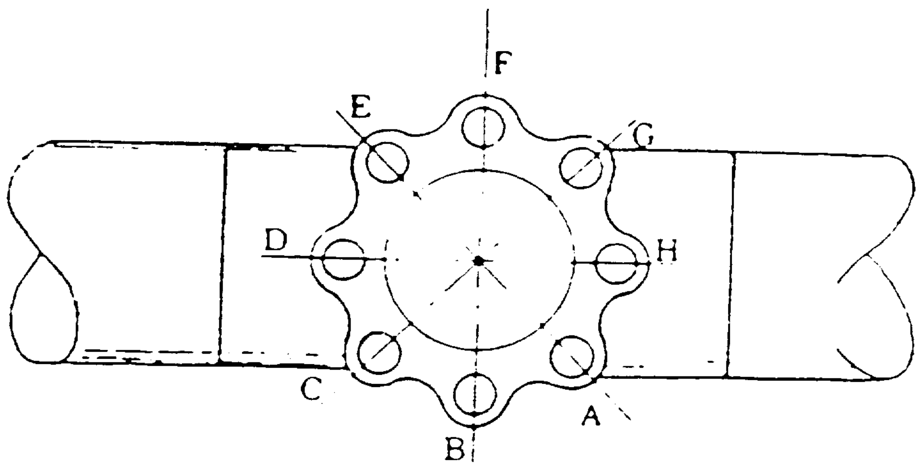

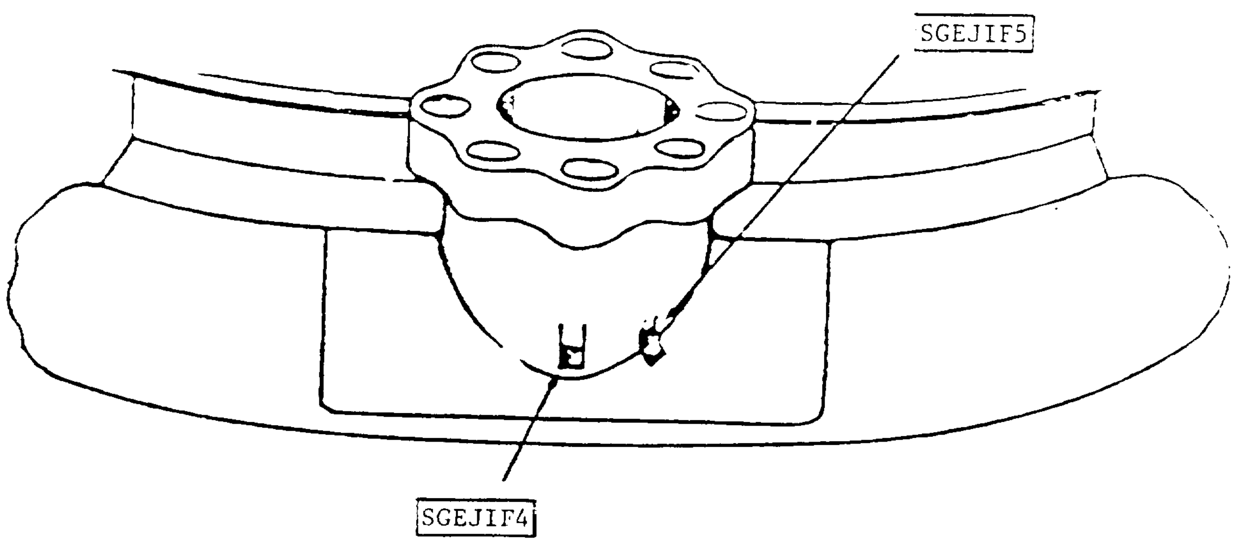

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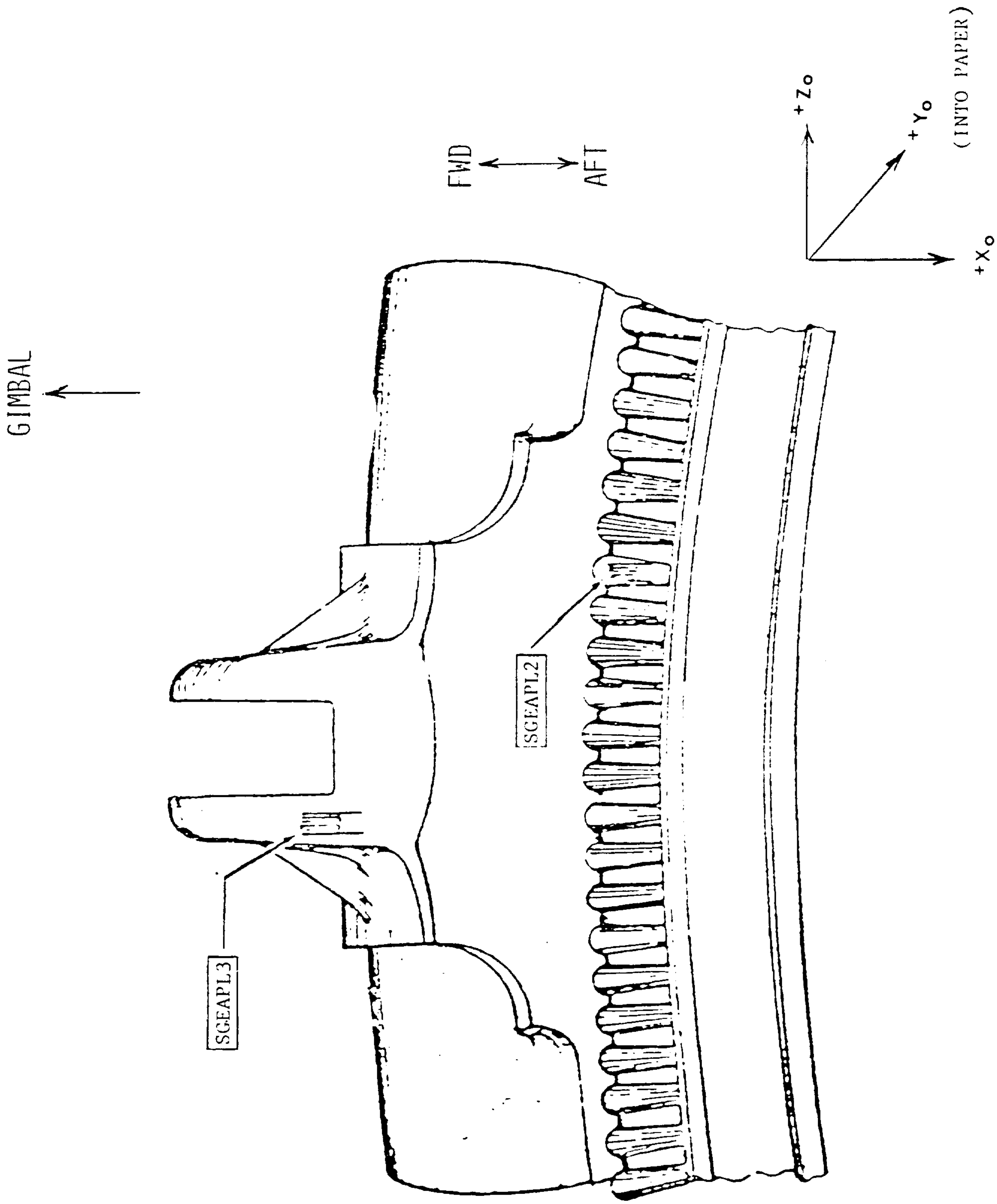

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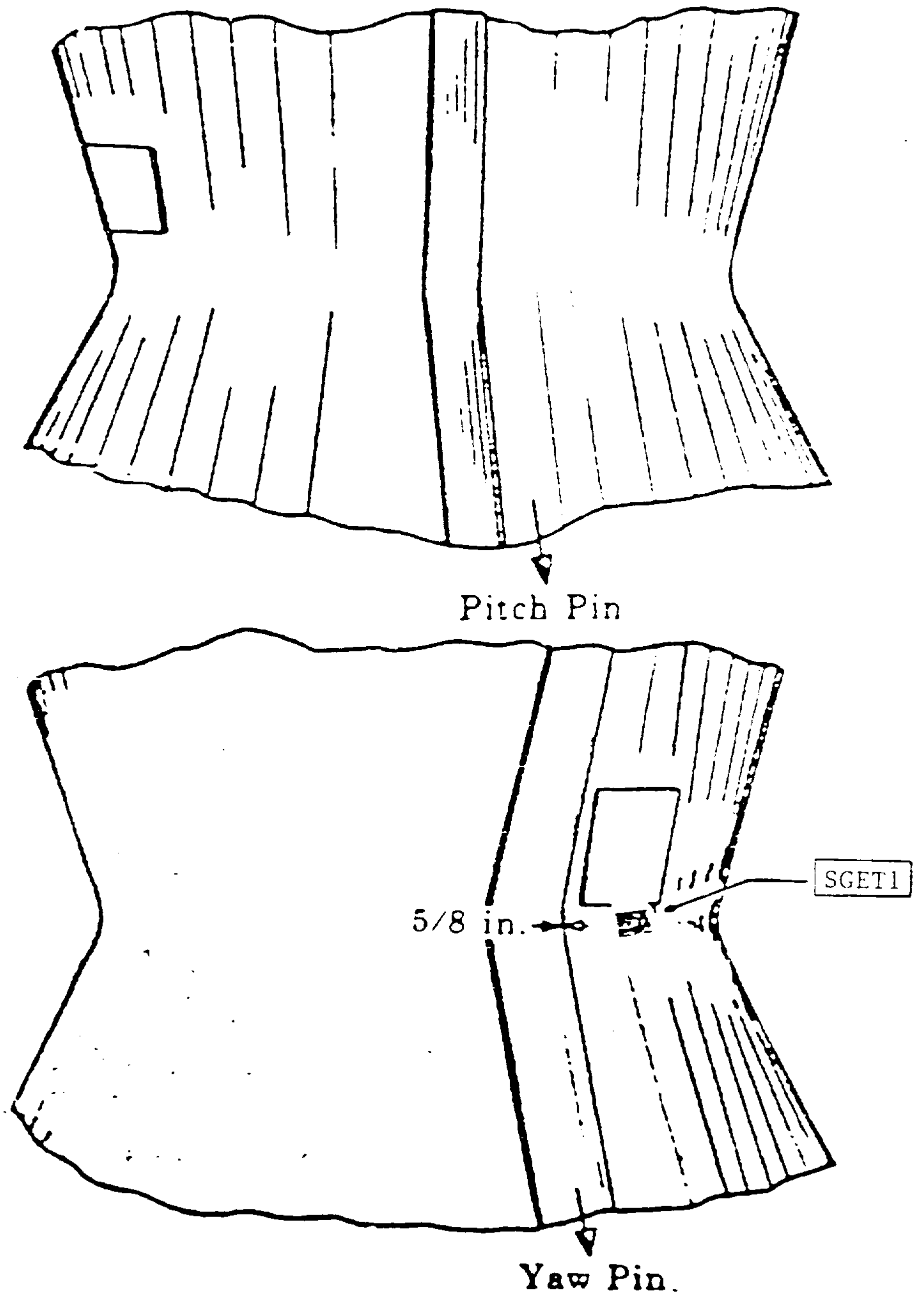

FIGURE 9

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